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The dissertation topic is: “Methodological and software-information support for automated control of energy resource efficiency in multi-stage production of high-quality flat glass”.

Relevance of the research topic. The problem of rational use of raw materials and fuel and energy resources is especially important for energy-intensive industrial productions, which include multi-stage production of high-quality flat glass (HQFG), representing complex chemical-technological systems (CTS).

The presence of a wide range of unresolved research problems from the standpoint of system analysis and methodology for applying various “Industry 4.0” tools related to the development of mathematical, algorithmic, and software-information support for automated control of energy resource efficiency in multi-stage HQFG production has led to the formulation of the aim and objectives of this dissertation research.

The aim of the research is to develop methodological and software-information support for automated control of energy resource efficiency in multi-stage HQFG production based on the application of optimal decision-making methods, multi-scale mathematical and computer modeling methods, artificial intelligence theory methods, and extensive use of modern information and communication technologies and “Industry 4.0” tools.

To achieve this objective, the following interrelated scientific and technical tasks were formulated and solved:

1. Conducting a system analysis of multi-stage HQFG production as an object of automated control.
2. Development of mathematical and computer models of chemical-technological processes (CTP) (batch preparation, glass ribbon forming, glass sheet packaging) of multi-stage HQFG production as control objects.
3. Development of intelligent and statistical algorithmic support for an automated system for diagnosing point defects in HQFG.
4. Development of algorithmic support for hierarchical automated control of energy resource efficiency in multi-stage HQFG production as a complex CTS.
5. Computer engineering of application software packages (ASP) for automated control of energy resource efficiency in multi-stage HQFG production.

6. Development of scientifically grounded recommendations for the practical application of ASP for automated control of multi-stage HQFG production in order to improve the energy resource efficiency of competitive industrial productions.

Scientific novelty of the research:

1. A neural network model for automated control of the composition of glass batch has been developed, distinguished by the use of a multilayer artificial neural network with feedforward signal propagation and backpropagation of the error during automatic training, which makes it possible to ensure the required technological operating mode of the dosing-mixing line under fluctuations in chemical and granulometric composition and moisture of raw materials (corresponds to p. 4 of the research field).

2. Mathematical and computer models of the CTP of continuous glass ribbon forming have been developed, distinguished by accounting for the influence of tensile stresses from edge-forming machines on the molten glass flow, which makes it possible to analyze various normal and emergency modes of glass ribbon forming on molten tin and to create software for a digital simulator for personnel training in normal and emergency situations (corresponds to p. 4 of the research field).

3. An algorithm for automated diagnostics of point defects in HQFG has been proposed, distinguished by the application of image analysis procedures of HQFG based on the wavelet transform method for defect localization, the use of an artificial neural network for recognizing the contour type of a point defect, and a set of heuristic rules for classifying the type of detected point defect, which makes it possible to automatically generate an electronic defect map of HQFG, the use of which ensures effective functioning of the system for automatic optimal cutting of the glass ribbon in real time (corresponds to p. 2 of the research field).

4. A probabilistic-statistical algorithm for analyzing the life cycle (LC) stages of multi-stage HQFG production has been proposed, distinguished by the use of the apparatus of Markov processes and a state graph for the stages of the HQFG production life cycle, developed on the basis of an extended classification of the levels of functioning of CTP, which makes it possible to determine the probabilities of the production being at each stage of its life cycle, necessary for automated calculation of reliability indicators and efficiency indicators of HQFG production (corresponds to p. 7 of the research field).

5. The architecture and operating modes of an ASP for computer-aided design of automated process control systems (APCS) for HQFG production have been developed, distinguished by the use of computer models for predicting performance indicators of CTP and procedures for determining equipment condition characteristics, which ensures a reduction in the

number of irrational design decisions, as well as reduced design and commissioning time of APCS for HQFG production (corresponds to p. 12 of the research field).

6. The architecture and operating modes of ASP for diagnosing point defects in HQFG have been developed, distinguished by the use of an optical-wavelet method for defect localization in HQFG and a neuro-heuristic algorithm for classifying defect types, which makes it possible, based on the use of standard hardware, to ensure automatic diagnostics of the most common point defects in HQFG (corresponds to p. 12 of the research field).

7. The architecture and operating modes of an ASP for a digital simulator for training personnel of the glass ribbon forming section have been developed, distinguished by the use of systems engineering methods for software engineering and a computer model of the CTP of continuous glass ribbon forming, which ensures advanced training of production personnel and their training for operation in normal and emergency situations (corresponds to p. 12 of the research field).

Practical significance of the research. The theoretical results of the conducted research have been practically applied in the development of a number of projects, in the implementation of measures and strategies for improving energy resource efficiency both in glass industry enterprises and in a number of other continuous complex multi-stage CTS. The results of the dissertation were used in the execution of research work under 10 contractual research projects with industrial enterprises. The originality and technical novelty of a number of technological solutions proposed in the work are protected by intellectual property certificates.

The following main results of theoretical research of scientific and practical significance are submitted for defense:

1. A neural network model and algorithm for automated control of glass batch composition to ensure specified technological operating modes of the dosing-mixing line under fluctuations in chemical and granulometric composition and moisture of raw materials.

2. A computer model of the CTP of continuous glass ribbon forming, allowing analysis of various normal and emergency modes of glass ribbon forming on molten tin and enabling the creation of ASP for simulators for personnel training in normal and emergency situations.

3. An algorithm for automated diagnostics of point defects in HQFG, enabling automatic generation of an electronic defect map used for efficient operation of the system for automatic optimal cutting of the glass ribbon in real time.

4. A computer simulation model of the life cycle stages of HQFG production, providing automated calculation of reliability indicators of HQFG production.

5. The architecture and operating modes of ASP for computer-aided design of APCS for HQFG production, ensuring a reduction in the number of unjustified design decisions, as well as reductions in design time and commissioning time of APCS for HQFG production.

6. The architecture and operating modes of ASP for diagnosing point defects in HQFG, ensuring automatic diagnostics of the most common point defects in HQFG.

7. The architecture and operating modes of ASP for a digital simulator for training personnel in the CTP of glass ribbon forming, ensuring personnel qualification improvement and training for operation in normal and emergency situations of HQFG production.

8. Scientifically substantiated engineering and technological recommendations for the practical use of the developed ASP for automated control of energy resource efficiency in multi-stage HQFG production.