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AUTOMATIZATION DESIGN OF FLEXIBLE SYSTEMS FOR MANAGEMENT WITH DECENTRALIZED CONTROL

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Abstract. This article examines automated control systems for complex technical complexes using the Tracemode software environment, which enables efficient management of industrial processes and the design of control systems. The objective of the study is to identify effective methods for managing complex industrial processes using decentralized and hierarchical control systems. The tasks include management of autonomous local blocks, use of Tracemode 6 for computer-aided design, simulation of industrial signals, and development of students' practical skills. Using Tracemode 6, students can monitor processes virtually, manage projects remotely, and utilize embedded libraries and ready-made blocks to develop practical skills. The software environment allows the creation of modules for economic and personnel management. Video tutorials, webinars, and online practical sessions provide international access to education. Tracemode engages students in research activities, project integration, and simulation of industrial processes, enhancing hands-on experience. Applying Tracemode improves the training quality for engineering, technical, and economic specialties. Its flexible and modular structure allows students to create integrated projects, control industrial processes, and conduct experiments, bridging theoretical knowledge and practical skills effectively.

Keywords: Tracemode, automated control systems, decentralization, hierarchical control, computer-aided design, educational process, industrial processes

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ОРТАЛЫҚТАНДЫРЫЛМАҒАН БАСҚАРУМЕН БАСҚАРУДЫҢ ИКЕМДІ ЖҮЙЕЛЕРІН АВТОМАТТАНДЫРУДЫ ЖОБАЛАУ

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Аннотация. Бұл мақала күрделі техникалық кешендерді автоматтандырылған басқару жүйелері тұрғысынан зерттейді, Tracemode бағдарламалық ортасын қолдану арқылы өндірістік процестерді тиімді басқару мен жобалау мүмкіндіктерін қарастырады. Зерттеудің мақсаты – децентрализденген және иерархиялық басқару жүйелерін қолдану арқылы күрделі өндірістік процестерді тиімді бақылау әдістерін анықтау. Міндеттері: автономды локалды блоктар арқылы жергілікті басқару, Tracemode 6 бағдарламалық ортасында компьютерлік жобалау және өндірістік сигналдарды модельдеу, сондай-ақ студенттердің білімін практикалық тұрғыдан жетілдіру. Tracemode 6 қолдану арқылы студенттер өндірістік процестерді виртуалды түрде бақылауды үйренеді, жобаларды қашықтан басқаруды жүзеге асырады, дайын кітапханалар мен блоктарды пайдаланып практикалық дағдыларын дамытады. Бағдарламалық ортада модульдер құру арқылы экономикалық және кадрлық мәселелерді шешуге болады. Видео сабақтар, вебинарлар және онлайн практикумдар студенттерді халықаралық деңгейде оқытуға мүмкіндік береді. Tracemode ғылыми-зерттеу жұмыстарына қатысу, жобаларды біріктіру және өндірістік процестерді модельдеу арқылы практикалық дағдыларды жетілдіруді қамтамасыз етеді. Бағдарламалық ортаны қолдану инженерлік, техникалық және экономикалық мамандықтардағы студенттердің кәсіби дайындығын арттырады. Tracemode икемді, модульдік құрылымымен студенттерге интеграциялық жобаларды құруға, өндірістік процестерді бақылауға және эксперименттер жүргізуге мүмкіндік береді, бұл теориялық білім мен практикалық дағдыларды біріктіреді.

Түйін сөздер: tracemode, автоматтандырылған басқару жүйелері, децентрализация, иерархиялық басқару, компьютерлік жобалау, оқу процесі, өндірістік процестер

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Мүдделер қақтығысы: Авторлар осы мақалада мүдделер қақтығысы жоқ деп мәлімдейді.

АВТОМАТИЗАЦИЯ ПРОЕКТИРОВАНИЯ ГИБКИХ СИСТЕМ УПРАВЛЕНИЯ С ДЕЦЕНТРАЛИЗОВАННЫМ УПРАВЛЕНИЕМ

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Аннотация. Статья посвящена исследованию автоматизированных систем управления сложными техническими комплексами с использованием программной среды Tracemode, позволяющей эффективно управлять промышленными процессами и проектировать контрольные системы. Цель исследования – определить эффективные методы управления сложными производственными процессами с применением децентрализованных и иерархических систем. Задачи включают управление автономными локальными блоками, использование Tracemode 6 для компьютерного проектирования, моделирования промышленных сигналов и развитие практических навыков студентов. С использованием Tracemode 6 студенты могут виртуально контролировать процессы, управлять проектами удаленно, применять встроенные библиотеки и готовые блоки для развития практических навыков. Программная среда позволяет создавать модули для решения экономических и кадровых задач. Видео уроки, вебинары и онлайн-практикумы обеспечивают международный доступ к обучению. Tracemode способствует участию студентов в научно-исследовательской деятельности, объединению проектов и моделированию производственных процессов, развивая практические навыки. Применение Tracemode повышает качество подготовки студентов инженерных, технических и экономических специальностей. Гибкая и модульная структура позволяет создавать интегрированные проекты, контролировать процессы и проводить эксперименты, объединяя теоретические знания с практическими навыками.

Ключевые слова: tracemode, автоматизированные системы управления, децентрализация, иерархическое управление, компьютерное проектирование, образовательный процесс, производственные процессы

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Introduction.

The article focuses on the management of objects that significantly differ from the traditional management of classical complexes, being considered as complex technological systems . Complex technological systems constitute a substantial part of industry, where a large number of technological regimes and industrial scales must be controlled, often through the integration of various mathematical and physical models. Examples of such objects include corporations, plants, workshops, and both small and large enterprises. The complexity of these technological systems arises not only from the technological processes and technical organization but also from specific economic laws (Mailybaev, 2019: 113–116).

Managing such objects requires a novel approach due to their unique functions. The theory of object management is based on a systematic approach, which accounts for the interrelations between individual system elements and factors and characterizes the behavior of the system as a whole. One method is the decomposition of the management system, which divides a system into separate subsystems. This decomposition simplifies complex tasks into manageable units, each of which is solved within its subsystem.

A key feature distinguishing complex technological systems from traditional management objects is the existence of purposeful functions within each subsystem. Notably, the local functions of subsystems often do not coincide with the global objective function of the entire system. In decision-making, subsystems tend to maximize or minimize their local functions under existing constraints, which may vary according to the significance of incoming parameters.

Management systems of large-scale objects are often structured as distributed, multilevel systems. The coordinating body at the top of the hierarchy makes system-wide decisions and interacts with all subsystems at lower levels. Decisions are reached through an informational exchange between the coordinating authority and subsystems, aiming to optimize both local and global objective functions.

The development of integrated automated control systems, which manage both technological processes and production-economic activities simultaneously, represents a natural progression of large system theory. For instance, the integrated software environment Tracemode exemplifies automatic programming and control in production, illustrating the practical application of flexible decentralized control systems.

The aim of this study is to demonstrate methods for building flexible, decentralized management systems in complex technological systems, using Tracemode as a case study. This includes mathematical modeling, decomposition of management tasks, hierarchical control, and integration of subsystems to achieve optimal system performance.

Materials and methods.

The principal feature of complex technological systems, compared with traditional management objects, is the presence of a purposeful function in each subsystem. It should be noted that the local purposeful functions of subsystems do not coincide with the global purposeful function of the entire complex (Morokina, 2019: 218). When making decisions, each subsystem aims to maximize or minimize its objective function among multiple possible alternatives, defined by all existing constraints; thus, an extremum problem is solved, and its specific data can change depending on the significance of input parameters (Umbetov, 2013: 85–89; Jose, 2015: 48–52).

Management systems for large-class objects are often structured as distributed, multilevel systems. The decision-making body at the system-wide level, called the coordinating authority, maintains bidirectional connections with all subsystems at lower hierarchical levels. Decisions are made through informational exchange between the coordinating authority and subsystems, where coordinating parameter values are communicated, and subsystems optimize their local functions accordingly. The resulting decision represents an agreed-upon solution between the coordinating authority and subsystems, achieving the optimal value of objective functions.

Key features of complex industrial systems include (Shukaev, 2013: 90–92):

- A large number of nodes,
- Complexity of various interconnections,
- Connections in the form of information, material, or energy flows,
- Human involvement in system operations,
- Presence of subsystems with local objective functions,
- Optimization of these functions during production.

The introduction of integrated automated control systems, which manage production and technological processes simultaneously, is a logical evolution of large systems theory. For example, the Tracemode integrated software environment enables automatic programming of measurement and control systems.

Flexible systems design with decentralization: Practical problem-solving requires consideration of information flows and their interactions. Decision-making often employs heuristic methods at the subsystem level, producing a decision vector that is refined at lower hierarchy levels (Morokina, 2019: 1–5) (Figure 1).

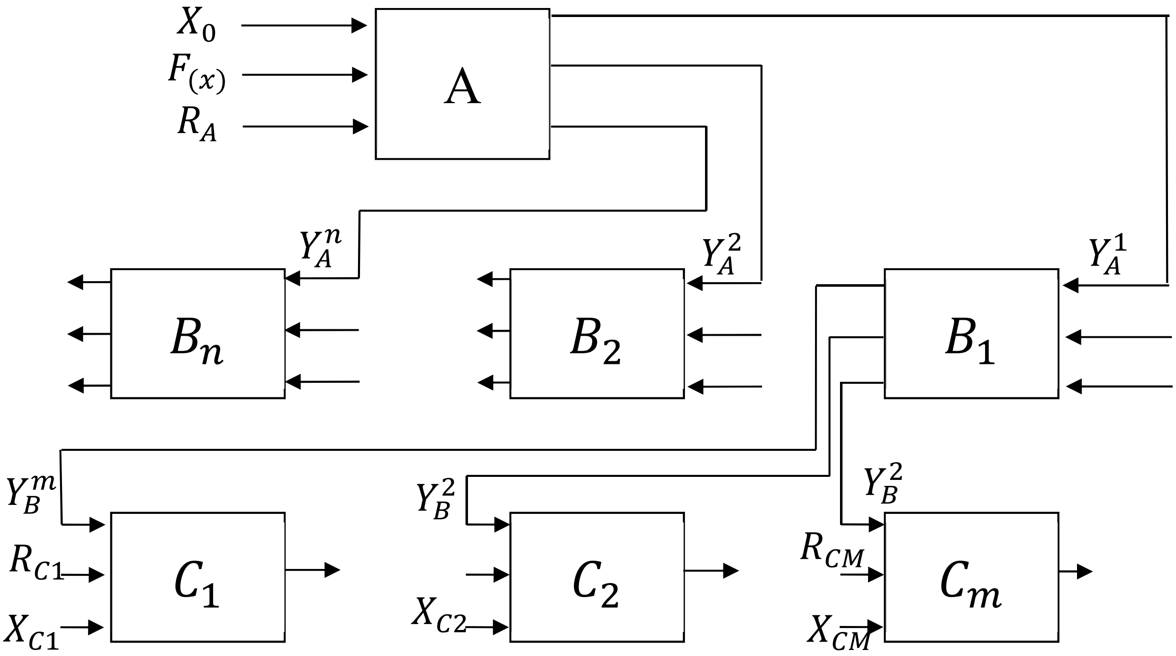


Fig. 1. Information flows in hierarchical control systems. $F_A(x_0)$ - the target function, R_A - the set of feasible solutions, X_A - the vector of the system state, Y_A - the control actions (Morokina, 2019: 1–5)

The path of the control signal from the coordinating body to the production element traverses various systems via the operators of the controlling parts of the subsystems. Here the properties of the subsystems become clearly manifested, especially due to human participation in their operation (Umbetov, 2013: 85-89). Such elements are often called active (Morokina, 2019: 1–5).

The active element has its own target function, which in most cases differs from that of the central part. This function is often unknown to the central part and may change over time depending on circumstances affecting the subsystems (Morokina, 2016b: 101-103). Naturally, when devising a solution, the governing body of the subsystem always seeks to maximize its target function. Other features of active elements are to some extent related to those already noted. The active element may be aware of the main provisions of the strategy of the central authority. The subsystem maximizes its target function not only in the present but also in future periods, and its strategy takes account of this fact, giving it a chance to compensate for possible losses (Morokina, 2019: 1–5; Umbetov, 2015: 273-275).

Subsystems have a choice between two strategies (1 and 2) (Umbetov, 2016c: 147-149). The effect of applying these strategies over time varies. However, when solving optimization problems, the subsystem typically takes into account future criteria with a time-dependent coefficient k(t)k(t), so if we take this property into account, the target function can be expressed, for example, as:

$$J = \int_0^T k(t) \cdot \bar{J}\,(t)\mathrm{dt}$$

where *J(t)* is the value of the optimality criterion in time, *k(t)* is the weight coefficient, *T* is a sufficiently long time interval. The properties of the function k(t) depend on factors, mainly of a psychological nature.

Many well-known examples of this property's manifestation by an active element can be given (Morokina, 2014a: 398-400). The subsystem generates information supplied to the centre so as to maximise its target function. This understandable property most often manifests in transmission of information about the true capabilities of the production unit. It is also important to note that, in contrast to technical systems, true information that is disadvantageous to the subsystem cannot be obtained even by observation or experimentation. The implementation of the central authority's strategies is not fully carried out by the subsystem, but only to some degree, in order to comply with all constraints in solving the problem.

Setting optimal control tasks as considered below are characteristic of many industries because of the widespread use of automated systems of various levels in the energy, machinery, instrument-making, chemical and other industries. The use of a decomposition approach to their solution is promising in terms of building hierarchical control systems. The introduction of flexible automated control systems, based on the latest achievements in control theory, advanced hardware and technical support using microprocessor-based computing equipment and wide application of controllers for various purposes, can be considered one of the main directions of production development and improvement at the present stage (Umbetov, 2016: 147-149).

When designing a decentralized control system for an industrial object of the class of a complex technological system (CTS), in order to ensure the flexibility characteristic of the CTS, it is necessary to consider possible changes in its structure. The structure of the CTS is understood as the totality of its elements and the relationships among them. Reorganisation of the CTS's structure is required when a number of influencing factors change, for example, indicators of raw-material quality, indicators of technological production mode, demand for products, etc. (Umbetov, 2016: 147-149; Morokina, 2016b: 101–103).

Let us consider the essence of the stated approach. The state of the CTS is uniquely determined by its structure and the values of the mode variables for each element of the system. We consider the problem of constructing an optimal CTS with a flexible tunable structure. As the criterion of optimal functioning of the system, we take a qualitative indicator of the product being produced, which is an additively separable function of the state variables of the system (Umbetov, 2013: 85–89; Umbetov, 2016c: 147–149).

Suppose that the system is in a certain state, determined by the vector of determining factors W^i, i = 1, m, where m is the number of different vectors. If at time t vector W^i, changes to W^{i+1}, then it is necessary to change the state of the system, which must be optimal in accordance with the selected criterion of the quality of functioning of the CTS. In this case, it is necessary to solve the optimization problem, consisting of two interconnected subtasks - the choice of the optimal structure of the system and the determination of the values of the mode variables with the changed structure of the CTS.

Let's consider the subtask of choosing the optimal structure of the system. We will introduce the set of $W=\{W^i\}$, i = 1, .., m - the set of vectors of the determining CTS factors and the set of possible structures of the system $S=\{S_k\}$, k = 1, .., L, where L is the number of admissible structures CTS, uniquely determined by the type of specific technological process.

We define a mathematical description of the structure S_k. Each structure of the system is described by a square matrix $A=\|a_{ij}\|$ of dimension (n * n). The elements of the matrix take the following values (Umbetov, 2016c: 147-149):

- $a_{ij} = 1$, if the connection between the i and j elements is possible,
- $a_{ij} = 0$ otherwise.

If the i-th element is off, then $a_{ij}=0$, j = 1, .., n. Matrix A can be corrected by introducing new connections between elements or excluding existing ones.

Let us introduce the matrix of changes in the structure of the system B=$\|B_{\text{ij}}\|$ of dimension (n * n). The element $B_{ij}=-1$, if the connection between the i-th and j-elements is excluded, if the connection between the i-th and j-th elements is not broken or does not exist, then $B_{ij}=0$.

The matrix B is a control action on the structure of the system, i.e. it implements on / off control of system elements.

The structure of the system at some point in time is described by the matrix of the current D=$\|d_{\text{ij}}\|$,, i, j = 1, .., n, where $d_{ij} = 1$, if there is a connection between the ith and jth elements and $d_{ij} = 0$ otherwise. The matrix D is the composition of the matrices A and B, i.e. D = A + B (Umbetov, 2016: 147-149). Thus, the elements of the set S can be described by a set of matrices D^k (k = 1, ..., n).

Mathematically, the static optimization problem of a flexible CTS is written similarly to an optimal control problem for a decentralized control system (Umbetov, 2013: 85–89):

$$\max_{D^k}\max_{x,u,y}\sum_{i=1}^{n} f_i(x_i, D^k, u_i, y_i) \tag{1}$$

$$y_i = g(x_i, u_i), h_i(x_i, u_i, y_i) \geq 0 \tag{2}$$

$$D^k = A + B,\ C_{\text{ij}} = \psi\left(D_{\text{ij}}^k\right) \tag{3}$$

$$x_i = \sum_{i=1}^{n} C_{\text{ij}} y_j, i, j = 1,\dots, n; k = 1,\dots, L \tag{4}$$

- where x_i, u_i, y_i are the vectors of the input, control, and output variables of the i-th element, respectively; fi (x_i, D^k u_i, y_i) is the target separable function describing the efficiency of the i-th element; g (x_i, u_i) is a vector function that determines the relationship between the variables of the i-ro element;

- hi (x_i, u_i, y_i) is a vector function that takes into account constraints on variables; Cij is the connection matrix between the jth output and the i-ro input; the operator ψ characterizes the connection between the elements of the submatrix D D^{k}_{ij} of the matrices D^k and C_{jj} (Umbetov, 2016: 147–149).

The equations (3) allow us to determine the values of the elements of the matrices C_{jj} when passing from one structure to another.

In the static optimization problem (1) - (4), it is necessary to find the maximum of the objective function by choosing a certain system structure and variables that determine the functioning modes of the elements of the CTS. This task can be solved by enumerating all the structures of the system. Moreover it is necessary to optimize the mode variables for each fixed structure D^k. However, this approach is ineffective, since it requires a lot of machine time. For this reason, the solution of problem (1) - (4) is conveniently divided into two stages. At the first stage, the problem of choosing the optimal structure is solved, at the second stage, when the fixed structure is found, the suboptimal values of the mode variables are determined (Umbetov, 2016: 147–149).

The problem of structural optimization is proposed to be solved using the principles of pattern recognition. To do this, we need to find a subset of structures $S_j \subset S\left(\cup S_j = S, S_i \cap S_j = 0\right)$ that are close to optimal, and then choose the optimal structure among this subset, which is much smaller than the set S.In solving this problem, we use classification methods that allow us to put a certain subset of S_j structures in accordance with each vector of the determining factors W^i. For this we divide the set S into classes according to the technological principle. Then, based on the experimental data and expert estimates (Umbetov, 2016c: 147-149), we find a correspondence between the classes of the set S and some subset $W*W$. Using W* as the training material, a classification rule is constructed that allows the set of W^i to be divided into subsets or classes. Such a partition can be done using the method of group arguments accounting. The classification W defines a class of structures close to optimal. Next, to find suboptimal structures needed to make the enumeration of all structures within the selected class. This solves the problem of parametric optimization (1) - (4) with a fixed D^k structure. This problem is distinguished by complexity and large dimension. The objective function and constraints are nonlinear, so it is proposed to use the methods of decomposition and nonlinear programming (Umbetov, 2016c: 147–149).

Implementation of hierarchical management of a large production complex involves:

- Substantiation of the existence of an optimal state, or coordination conditions;
- Development of algorithms for finding the optimal state and ensuring high efficiency and convergence speed (Umbetov, 2016c: 147–149).

When building complex automated systems with the Tracemode software environment, the above algorithms are used to develop flexible, decentralized systems (Umbetov, 2013: 85–89; Morokina, 2016b: 101–103). Features of optimal control of complex technical complexes include:

High complexity due to many variables and relationships;

Natural division into subsystems, each with a local control problem;

Iterative hierarchical management through information exchange;

Decomposition of the original control problem into interrelated local problems;

Coordination procedures interpreted as finding optimal global solutions (Morokina, 2014: 398–400).

Computer-aided design problems can be solved in Tracemode6, integrating components of measuring systems, programming projects, and production management modules (economic, personnel, etc.) (Umbetov, 2015: 273–275). The FBD language and other programming languages in TRACE MODE (Techno SFC, Techno LD, Techno FBD, Techno ST, Techno IL) allow creating mathematical models for educational and industrial purposes (Umbetov, 2013: 85–89; Umbetov, 2019: 218–221).

Modules such as EAM – management of fixed assets, maintenance, and repairs in T-FACTORY 6 enable creation of control programs considering downtime and operational features of equipment (Morokina, 2016a: 140–141). Remote access and mobile devices further allow project management and process monitoring.

Results and discussion.

When building complex automated systems using the Tracemode software environment, it is necessary to take into account the developed algorithms for constructing flexible decentralized systems. The main conclusions regarding the features of optimal control of production facilities in the category of complex technical complexes can be summarized as follows:

High complexity of control problems: These systems involve a large number of variables and numerous functional relationships, making it difficult to apply traditional centralized management methods and necessitating hierarchical management systems.

Natural division into subsystems: The system can be divided into components or subsystems, each controlled by an autonomous system that solves local control problems. The overall control system thus has a multilevel hierarchical structure, with local control systems coordinated by a central management body at the highest level.

Iterative hierarchical management: Hierarchical management is implemented as an iterative, typically multi-step procedure of information exchange. Each subsystem solves its own control problems while the values of coordinating parameters are selected based on a global optimization strategy that considers system-wide constraints (Shukaev, 2013: 90–92).

Decomposition of control problems: Building hierarchical control systems requires decomposing the original global control problem into interrelated local problems. The joint solution of these local problems determines the solution of the original global problem. The choice of parameters and coordination method depends on the decomposition approach

Coordination as global optimization: The procedure for coordinating local problems can be interpreted as finding the optimal solution for the global management problem, achieved through equilibrium solutions derived from joint solutions to all local problems at each coordination step.

The solution of production problems with decentralization is implemented in the Tracemode6 software environment. For example, the creation of computer-aided design and control systems that integrate individual components of a measuring system is possible using the domestic Tracemode environment, which is rapidly developing and widely used in industry (Umbetov, 2015: 273–275; Morokina, 2016b: 101–103). In addition to programming projects and data broadcasting via information transmission, Tracemode6 allows the creation of separate production management modules addressing economic issues, personnel management, and other aspects (Figure 2).

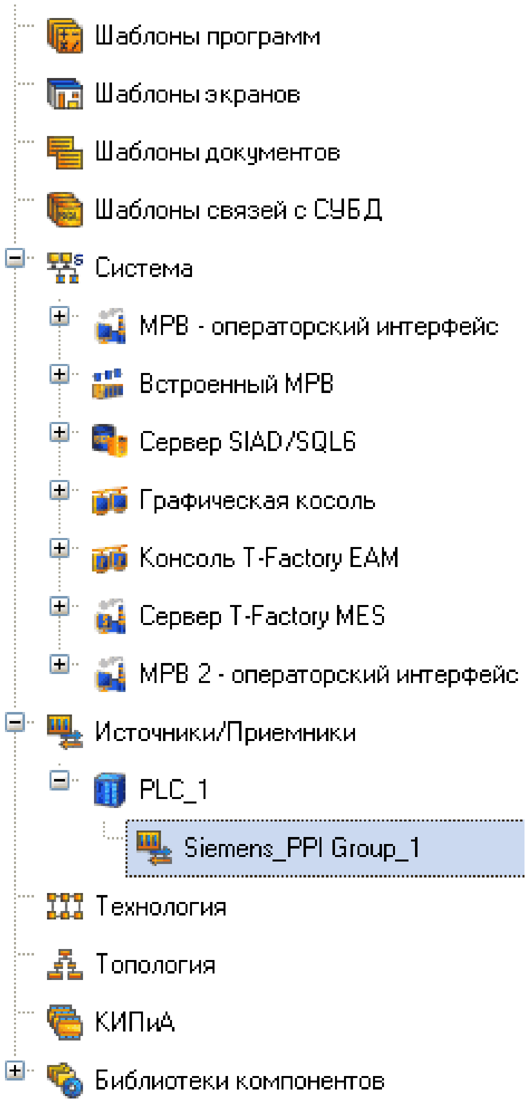


Fig. 2. Menu of production management modules taking into account economic, personnel issues, etc.

The FBD (Function Block Diagram) programming language within Tracemode allows users to program mathematical functions visually, as introduced in laboratory works for disciplines such as “Basic Design of Devices and Systems” and “Fundamentals of Product Design” for instrument-making students (Umbetov, 2013: 85–89). The system supports five modern programming languages—Techno SFC, Techno LD, Techno FBD, Techno ST, and Techno IL—providing extensive demonstration material for both technical (instrumentation) and economic disciplines, as well as for production control and management (Figure 3).

Program templates and system components include:

- Program templates
- Screen templates
- Document templates
- Database connection templates
- System operator interfaces (MRV, built-in MRV, MRV2)
- SIAD/SQL6 server
- Graphical console
- T-Factory EAM console
- Sources/Receivers (PLC_1, Siemens PPI Group_1)
- Technology, Topology, Instrumentation, Component library

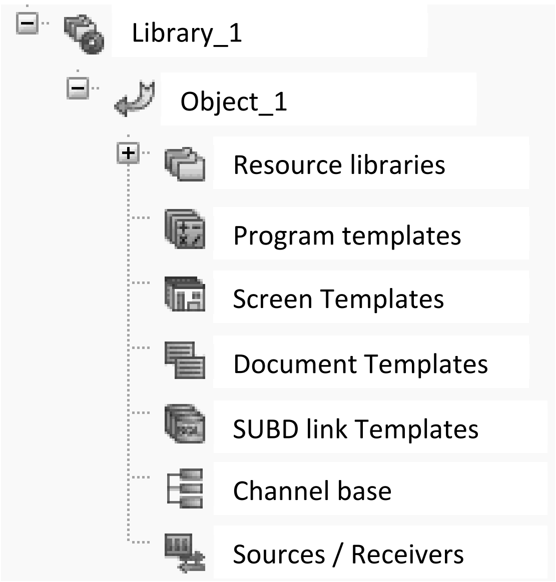
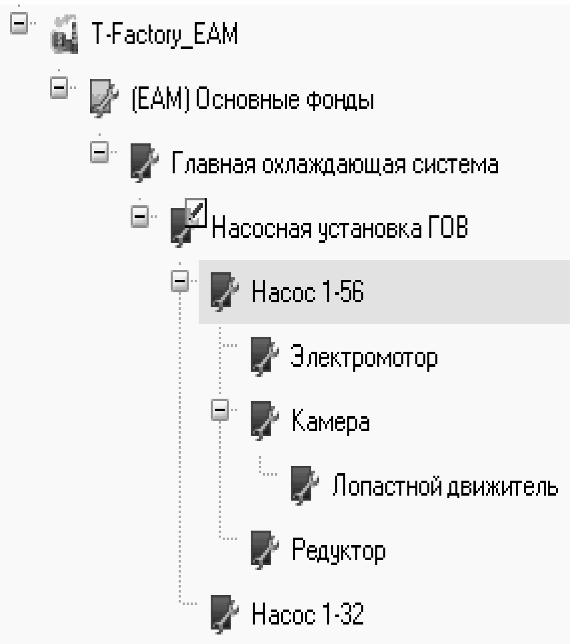


Fig. 3. Basic program templates for building a measuring system

For example, Modules such as EAM – management of fixed assets, maintenance, and repairs in T-FACTORY 6 allow creation of control program fragments that account for equipment downtime, repairs, and operational features of production resources (Umbetov, 2019: 218–221).

When creating computer-aided design and control systems, building control devices for various purposes, which allow using the created analog instrument on the PC monitor as a recording device, the measured parameter is specified in the “text” column. When creating a node in the project, an auto building procedure is used, a group of sources / receivers is created, and a signal generator is selected: a saw, a sinusoid, a random number, etc. (Umbetov, 2019: 218–221). Trend placement and data processing is the next stage, illustrating the operation of the newly created device and the possibility of Trace mode. DDE protocol communication with MS Windows using the example of Excel, as well as connecting a real external input signal module, allows to create a control system based on software such as the Trace mode 6 integrated software environment (Figure 4). For the development and demonstration of the transfer of data on the technological process from the production site to a remote point, it is possible to use the TM6 with the developed modules in the TRACE MODE software environment.



- T-Factory_EAM
  - (EAM) Основные фонды
    - Главная охлаждающая система
      - Насосная установка ГОВ
        - Насос 1-56
          - Электромотор
          - Камера
            - Лопастной движитель
          - Редуктор
        - Насос 1-32

T-Factory
(EAM) Fixed assets
Main cooling system
Pump installation GOV
Pump 1-56
Electric motor
Cell
Blade propeller
Gearbox
Pump 1-32

Fig. 4. Module - Process control of the pump section.

Using a cell phone allows not only the control of technological processes but also the creation of projects with remote access. The presence of well-equipped computer classes at the University of Mines enables students to be trained in this management-design technology from the early years of their studies. In addition to creating their own projects, students can use embedded libraries containing ready-made fragments of technological processes (Umbetov, 2019: 218–221). The integration of this software environment into the educational process facilitates research activities for undergraduates and allows students from other universities, both domestically and internationally, to participate via the Internet. Moreover, the use of video cameras and presentations enables the development of training programs for advanced students, the conduct of international webinars and seminars remotely (Umbetov, 2019: 218–221), and the delivery of online lectures and practical computer classes.

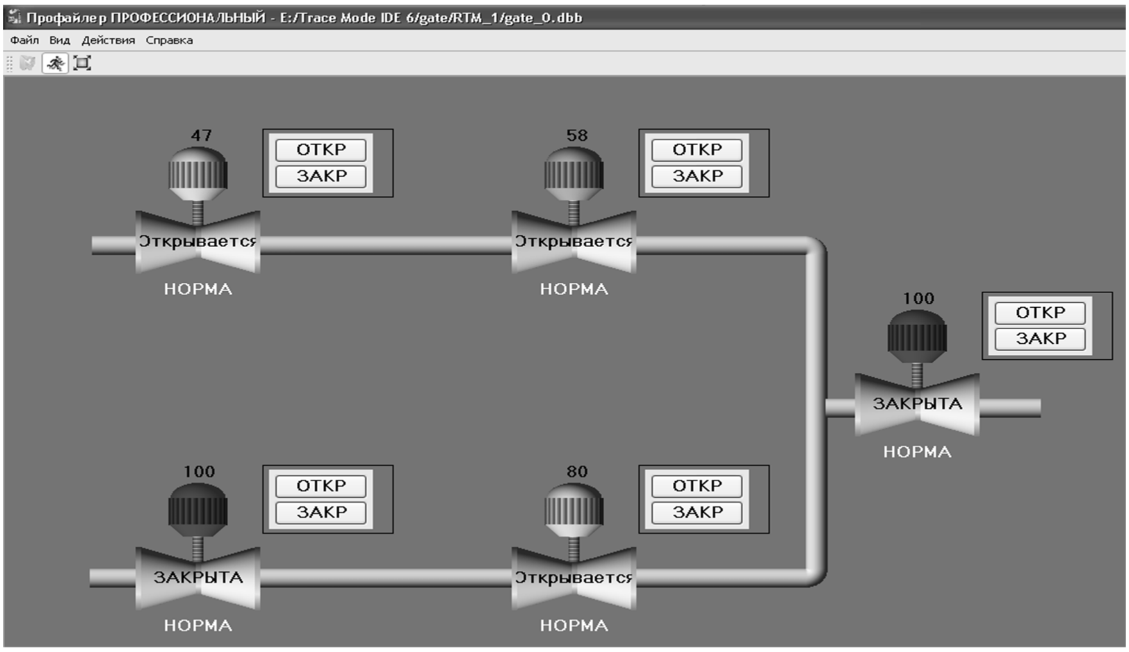


Figure 5. Programming the gate valve in the TraceMode project

Conclusion.

The analysis of the problem of designing and controlling complex technical systems (CTS) demonstrates that the development of flexible, decentralized control structures is essential for the efficient operation of modern production facilities. The fundamental challenge in managing such systems lies in the high complexity of control problems, which arises from the large number of variables and the intricate interrelationships between them. Traditional centralized control approaches often fail to address these challenges due to computational limitations and the difficulty of managing numerous functional dependencies simultaneously. As a result, hierarchical and decentralized control systems have become increasingly important in industrial automation and production management.

Hierarchical management allows a natural decomposition of the system into subsystems, each of which can operate autonomously while being coordinated by a central body at the highest level. This multi-level structure ensures that local control problems are solved iteratively, with continuous exchange of information between subsystems and the central management unit. The approach facilitates the selection of optimal operating parameters and the coordination of local tasks, ultimately leading to the global optimization of system performance. By decomposing the original control problem into a set of interrelated local problems, it is possible to simplify the computational complexity and achieve suboptimal yet practically effective solutions. Such decomposition is particularly advantageous for large-scale systems, as it enables stable convergence toward the global optimum while reducing the computational load associated with full enumeration or centralized optimization methods.

The integration of the TRACE MODE software environment into both industrial and educational contexts has shown significant practical benefits. In production facilities, Tracemode allows the creation of modular control systems that integrate individual measuring components, manage fixed assets, monitor maintenance schedules, and optimize production processes. The software's support for multiple programming languages (Techno FBD, Techno LD, Techno ST, Techno IL, and Techno SFC) provides a versatile platform for modeling complex systems using visual programming blocks. These tools facilitate rapid development, simulation, and testing of control strategies, while ensuring that the software remains adaptable to changing technological and operational conditions. The modular architecture also allows the implementation of parametric optimization and decentralized decision-making, ensuring that the system can respond dynamically to changes in production demands or technological factors.

From an educational perspective, the use of Tracemode in universities provides students with hands-on experience in modeling, designing, and controlling complex automated systems. Well-equipped computer laboratories, access to embedded libraries of pre-configured modules, and the ability to create projects remotely using mobile devices or Internet connections foster research-oriented learning. Students gain the opportunity to experiment with real-time data acquisition, signal generation, and process control, thus bridging the gap between theoretical knowledge and practical application. Moreover, the software supports remote training through webinars, online lectures, and interactive seminars, enabling collaboration across universities and international programs. This approach not only enhances the technical competencies of students but also prepares them to participate in research projects and industry applications at an early stage of their education.

In conclusion, the combination of hierarchical control principles, decentralized optimization, and the Tracemode software environment constitutes a robust framework for managing complex technical systems. This approach allows the efficient resolution of high-dimensional, nonlinear optimization problems, ensures adaptability to changing operational conditions, and facilitates both practical industrial applications and advanced educational programs. The development of flexible control architectures, supported by modular software tools and modern programming environments, represents a crucial step toward the automation of production processes, the enhancement of system reliability, and the preparation of future specialists capable of implementing and managing sophisticated technological systems. As industrial and educational demands evolve, the continued refinement of such methodologies and tools will remain essential for achieving optimal performance, fostering innovation, and maintaining competitiveness in increasingly complex technological environments.

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