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AUTOMATED ROBOTIC COMPLEXES IN ENGINEERING, ADJUSTMENT, PRODUCTION AND EDUCATION PROCESSES

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Abstract

Distributed monitoring and control systems are developed for automating the control of large-scale and complex industrial systems. They consist of a combination of digital and mechanical parts operating in complex processes, both deterministic and stochastic, inside and outside of the systems.
A feature of monitoring and control systems in large-scale and complex industrial systems is ability to collect, analyze and act based on a large volume of information in limited time periods. At the same time, large-scale and complex industrial systems have the properties of a flexible distributed production line.
The article analyses the modernization tasks of control and monitoring systems of large-scale objects by focusing on "Industry 4.0" technology. The prerequisites for creating and designing digital twins for components of such systems are considered. New technologies of automated electric drives setting up are proposed. The theoretical principles to assess an efficiency and probability to reduce an energy consumption in large-scale systems affected by significant external disturbances and interference is shown. It demonstrates the results of students and undergraduate education in the field of management of large-scale industrial systems within the framework of the international educational project "Synergy". The long-term objectives of artificial intelligence application for further research and improvement of large-scale systems are identified.

Keywords: large objects of control and monitoring, digital twins, robotic systems, design, commissioning, production, education, "Industry 4.0" technology, artificial intelligence.

1. Introduction

Features of the "Industry 4.0" technology, announced the same as "The Fourth Industrial Revolution", are the transition to fully automated digital production, controlled by intelligent systems in real time in constant interaction with the external environment, going beyond the boundaries of a single enterprise [1, 2, 3, 4]. The characteristics of "Industry 4.0" technology has practically unlimited important options in terms of performance measures: volume, speed, and methods of information flows transmission.

Within the framework of distance international learning associations (for example, the Synergy type [5]), it makes sense to consider, analyze and examine elements of control and monitoring of large-scale and complex industrial systems.

It is worth mentioning that not the number of technologically connected subobjects, but unlimited volumes of a priori, a posteriori and virtually obtained information is important. This sets and solves optimization problems that were previously limited for any reason.

Further as monitoring and control (M&C) system of large-scale industrial objects the combination of the following automation objects is considered:

- underground coal-mining complex with supervisory multilink control system for electric drives of machines and mechanisms [7], as part of the complex: longwall panel, consisting of hydraulic sections, with jacks and special constructions, fixing the excavated space in the mine face up to 200m long, that can contain up to 200 sections of support; coal-mining machine with controlled electric drives for cutting and feeding; oil pumping station; scraper conveyors along the mine face; belt conveyors on air-feeding slices up to 1000 and more meters long; special point for mined coal reloading; ventilation system; local control and monitoring systems; special software and hardware multilink supervisory control system; created elements of the digital twin of underground coal mining complex. In coal mining modes the complex is considered as an automated robotic complex.
- FESTO laboratory robotic installation with the unique remote-control system [8, 9] - robot manipulator, system of movement and transportation of structural elements of the equipment. Local control subsystem and hierarchical system with an open software and hardware subsystem that allows developing unique digital control systems. The FESTO laboratory unit is an automated robotic complex, and a digital twin of this unit is studies within the framework of the current work.
- FESTO laboratory bench with a tracking electric drive [10] is an electromechanical tracking drive of the working mechanism. Software and hardware component compatible with LabVIEW and MatLAB application program package. Local control subsystem and hierarchical system with an open hardware and software subsystem that allows developing unique digital control systems. The FESTO laboratory bench is an automated robotic system, and a digital twin of this unit is studies within the framework of the current work.
- laboratory bench of frequency-controlled DC and AC electric drives with specialized software and hardware system MexBIOS Development Studio [8, 11] is a laboratory bench of frequency-controlled DC and AC electric drives with specialized software and hardware system MexBIOS Development Studio [8, 11, 12]. The bench allows to investigate, and study automated electric drive systems.

2. Design of monitoring and control (M&C) system of large-scale industrial objects in the context of “INDUSTRY 4.0” technology

It is proposed to consider the process of M&C of complex industrial systems designing in the context of “Industry 4.0” technology using the example of underground coal mining complex. Despite the different approaches of the solution, the main problem of underground mining has previously been and remains for now is providing of safe extraction of rock. As part of solving the problem, the purpose, designation, features and characteristics of technological process objects are determined, in particular, a priori information concerning the characteristics of the mining face and the structural elements of technological equipment is carefully collected and studied [13]. A priori information is the starting material for the develop process of any technological object.

The analysis of technological process of coal mining is based on scientific papers of the Deputy Director of Ugleservis company, the Coal Department of the Arcelor Mittal Temirtau, Joint Stock Company, Associate Professor, D.E.Sc., Avdeyev L.A. [14, 15].

According to the technological process, the coal mining machine cuts the slice of coal face and moves it along the scraper conveyor to the upper part of the production face. In the face, along its entire length, sections of longwall panel with many structural elements to support the mined-out space, jacks for moving the conveyor and support sections, and routing of hydraulic drive and control hoses for the support sections are sequentially installed.

The Germany made Eickhoff SL coal mining machine with controlled cutting and feeding electric drives has been applied on flat and inclined coal seams of medium and above medium thickness in the mines of the Coal Department of Arcelor Mittal Temirtau, JSC (hazardous due to gas and dust).

The coal-mining machine SL 300 model is used for mining coal from seams with a thickness of 2 to 6 m. It is a complex engineering device weighing more than 150 tons, dimensions between the cutting drums axes - 12112 mm, diameter of two cutting drums - 2200 mm each, weight is 41 tons each, total installed power of electric drives is 688 kW, special systems for cooling electric motors and moving drums using hydraulic jacks, two feed mechanisms using gears and racks that are installed on a scraper conveyor stand.

The theoretical and practical problems for creating a supervisory multilink control system for electric drives of a coal mining machine were solved [16]. Based on the mentioned works [17], a hierarchical structure of an automated electromechanical underground coal-mining complex was proposed. The digital twin of underground coal-mining complex is designed within the framework of a functional hierarchical block diagram [17] and consists of many mathematical models and software analogues of machines, installations, electric drives and local control systems of the coal-mining complex. Some mathematical models and software analogues (for coal mining machines) were developed in [16]. The issue of replenishing the set requires efforts of qualified specialists.

The peculiarity of operating modes of technological elements of the coal-mining complex, defined in [16], is that in the process of mining and transporting coal the machines are subject to stochastic disturbances, i.e. normal operating modes are stochastic, and the startup and stop modes of electric drives of machines in this case should be considered as close to the modes of step, pulse and harmonic actions classified in the theory of automatic control as typical actions on dynamic objects. In relation to the coal-mining complex, we will call such start-up and stop processes standard machine modes. Specialized software "Digital Twin" allows you to virtually implement algorithms for the synthesis of optimal controls and multilink supervisory control, both in divided and real time modes.

The digital twin is a fundamentally new design since individual models of elements must be combined into a single whole and scenario compositions created that simulate processes in a coal mining face. The number of compositions will be the set M_{sd} = {NRE, TRM, ARE}, reflecting all possible situations under normal (NRM), standard modes (TRM) and emergency modes (ARE) of the operation of a mining machine. The tools for developing, adjustment, configuring and operating multiple operating modes are the MatLAB subsystems: MatLAB-Simulink, LabVIEW, Statictica, as well as the software for situational modeling SimEvents and Stateflow [18, 19].

"Industry 4.0" technology largely removes technical, software-algorithmic, computational and methodological restrictions for the design process. Here it is necessary to seek a compromise between the possible, truly necessary and sufficient level of decisions made.

The path to achieving sustainable results lies in setting technology-based priorities. In relation to the underground coal-mining complex, this is primarily: production safety; control of dynamic load, service life, reliability and energy saving of machines; quality of coal and the cost of mined coal subject to the fulfillment of production volumes within the framework of the necessary requests.

As part of the study of FESTO benches and installations and for the bench by the MexBIOS system with a rigid structure, but with software-algorithmic components allowing for variation in the design process, there can be solved the problems of creating and adjustment new intelligent software-algorithmic tools of control and monitoring individual components and objects as a whole.

3. Setting up and adjustment of M&C system of large-scale industrial objects in the context of "INDUSTRY 4.0" technology

In the review article [20], methods for setting up and adjustment regulators of automated electric drives are divided into two groups. The first group, called traditional, is focused on modular and symmetrical optimums, and is performed as a function of the time constants of the drive motor. This technique, developed in [17, 18, 19] works, was and remains a necessary stage in preparing an automated electric drive for operation.

The second group, associated with progress in the fields of power electronics and microprocessor technology, as well as with the advent of powerful specialized application software packages for instance MatLAB-Simulink [18, 19], MexBIOS [11, 12], contributed to the mass introducing of various variants of frequency-controlled electric drives, which significantly complicate the drive circuit technique and require recording when setting up and adjustment not only the dynamic properties of electric motors, but also frequency converters, analog-to-digital converters (ADC), digital-to-analog converters (DAC), data input-output, microprocessor devices of various types, programmable logic controllers (PLC) and PC devices.

Demand determines supply; accordingly, new power technology for automated electric drives required new setting up and adjustment technologies. Within the second group of techniques, we highlight two approaches:

1. The use of specialized bench-analogs for conducting physical experiments with subsequent large-scale transfer of the results obtained to an industrial automated electric drive [11, 12];
2. Setting up and adjustment of industrial electric drives using hardware and software simulators of a real-life electric drive [24, 25, 26].

We describe below in more detail both approaches for technology setting up and adjustment the power equipment of an automated electric drive.

3.1 Hardware and software simulators of real-life electric drives

Professor from the Ural Federative University, A.M. Zyuzev, developed a technology for setting up and adjustment an automated electric drive using hardware and software tools called "Controlled Electric Drive Simulators" [24, 25, 26].

Replacing the power part of an electric drive during setting up and commissioning processes using software and hardware simulators is effective in terms of maintaining the functionality of the new electrical equipment, reducing the cost of the setup process and the time for preparing the drive for operation. There are a large number of units and installations for which presence of the noted capabilities is the primary factor in operation processes (for example, oil production installations operating in harsh climatic conditions [24, 25, 26]).

Using the materials of work [25], which describes the creating process of a simulator of the power part of a modernized locomotive, which includes real-life mathematical models of the electric drive power parts.

In [25], the electric drive simulator is a set of tools that ensure interaction of a real-life electric drive control system with hardware and software tools used to simulate the electric drive system in real time at a frequency of 1 MHz.

Depending on the assigned tasks, electrical equipment simulators are developed to simulate in real time the operation of an electric motor, converter, converter-motor or converter-motor-mechanism systems. For example, to set up a converter control system, a simulator of the power part of an electric drive can be used, which receives control signals from the converter keys, models operation of the keys and the electric motor, and produces feedback signals necessary for the control system operation.

A hardware-software simulator may be based on a computer running a real-time operating system. Such simulators are fast enough to simulate systems containing a thyristor converter. Simulating the operation of a transistor converter requires higher performance, which can be provided by systems based on a digital signal processor (DSP) or programmable logic device (PLD). The latest version of simulators implementation has become widespread due to the high speed of PLD and the availability of convenient programming tools.

3.2 Setting up and adjustment technology of industrial automated electric drive using simulator benches

We propose an algorithm for setting up and adjustment a specific electric drive, for example, a pumping station of a heat supply system in a megalopolis or an electric drive of an oil-pumping station of an underground coal-mining complex equipped with asynchronous, frequency-controlled electric drives.

1. The nominal parameters of the original electric motor and electric drive (rated power, supply voltage, current, active and inductive resistance of the stator winding, energy conversion efficiency, rotor torque of inertia, actuator, gearbox) are evaluated.
2. The time constants of the electric drive, the reduced moment of inertia is calculated.
3. The design scheme of the electric drive is drawn up.
4. The electric drive operating modes are determined and the characteristic of braking torque on the motor shaft is evaluated.
5. Based on the similarity theory, the conversion factors of the original motor parameters into the motor simulator bench parameters are determined from the assumption of existence, in the first approximation of a linear dependence of parameters of the original and installed on the simulator bench asynchronous electric motors.
6. Subsequent actions of a commissioning engineer come to the development in the MexBIOS™ Development Studio environment of simulation models of an automated frequency-controlled electric drive with a load characteristic similar to that of the original motor for all possible options for constructing automatic control systems for an asynchronous motor of the simulator bench for subsequent transformation (using calculated similar coefficients) to the automated electric drive of a working mechanism.
7. According to the simulator bench operating technology, the results of simulation studies are verified through the physical implementation of each structural diagram of the simulation model on the real equipment of the simulator bench, followed by physical experiments in modes similar to the operating modes of the original electric drive of a working mechanism.

4. Developing of M&C system of large-scale industrial objects in the context of “INDUSTRY 4.0” technology

4.1 Prerequisites for the need to assess the M&C Systems durability.

In industrial production, a very significant factor (sometimes the most important) is the stochasticity of processes associated with the external environment of large-scale industrial systems. As a result, it is necessary to operate with probabilistic characteristics. Some theoretical results are shown in [27, 28, 29].

4.2 Assessment of durability ranges of technological machines and installations

The analysis object will be the elements of production plants and machines with rotating shafts driven by an electric drive and subject to stochastic disturbances [16].

These can be machines (for example, technical systems containing means of energy supply and movement of substances), stationary pumping and compressor stations, cutting drums of coal-mining machines, flexible automated production, which involves robot manipulator and conveyors are involved in interconnected work operations on structural elements of production (parts).

It is necessary to forecast the actual service life of machines.

Rotating machines operate in dynamic modes. In the works [16, 30], it is proved that in the function of deviations of rotational speeds and torque of motor and machine shafts it is possible to realize estimation of the spent resource of motos and machines as a whole.

In [16, 30], the machine reliability functionality is defined as the dependence of the probability of failure-free operation for the period of time between two overhauls from a variety of varying factors - machine operating conditions. The durability features are defined as the dependence of the time frame (years, hours), in the continuation of which with a probability of not less than the minimum possible level of machine reliability – σ_{Nmin} (on verge of operation risk), the machine will be in operating condition and will not require major repairs. We were talking about mining machines operating in significantly stochastic conditions. It is economically and technically sufficient to ensure the established design levels of minimum reliability and durability in the established period of machines operation [31].

In the works [16, 30, 31], it is established that machine's reliability and durability depends on intensity of dynamic processes occurring in gearboxes, electric drives and structural shells (cases) of machines, but there are no analytical dependencies of the reliability functionality of machines and the durability features from reliability level, durability period and other variable factors.

If in some way it is possible to determine the actual values of the reliability level (σ_N) and the service life period (T_D) of the machine for specific operating conditions, then these values can be used to predict operating modes of the machine that ensure that σ_N and T_D are maintained at the level $\sigma_N \geq \sigma_{Nmin}$, $T_D \geq T_{Der}$, where T_{Der} is the period of cost-effective durability of the machine.

Subsequently, the individual values of σ_N, T_D, as a function of the operating conditions existing for them, can be approximated graphically or analytically and used in the control system of machine operating modes.

The machines operating mode in technical systems is generally conditioned by the random character of changing the main disturbance (machine load), and then the angular velocities (ω) and torques (M) of parts are random (stochastic) processes. These processes' characteristics (mathematical expectations, dispersions, standard deviations) depend on control quality of the local automated electric drive or complex optimal control system. Here are additional reserves for increasing durability of controlled machines.

By putting the information about the duration of machine switching operating (t_{jt}) into the database of the hierarchical control system, M&C, it is possible to control the machine resource.

The data arrays $Y_j(t)$ contain information about the states of moments and angular velocities of elements and the duration of machines switching t_{jt}. The array data consists of two groups of elements: the first, corresponding to deterministic operating modes (on, off, hard work...); the second is stochastic, corresponding to normal operating conditions, is often characterized as stochastic.

In deterministic operating modes of technical systems of electrical complexes, the prevention of emergency situations must be ensured by hardware protection. If, in this case, the shaft rotation frequencies $\omega_j(t)$ and torques $M_j(t)$ do not exceed the limit values, then these situations should not lead to a decrease in service life in machines of electrical complexes, therefore, in the future, it makes sense to evaluate only the stochastic group $Y_j(t)$, t_{jt}. for reliability and durability of machines in technical systems of electrical engineering complexes.

4.2.1. Prerequisites for analyzing the energy efficiency of the M&C system of large-scale industrial facilities

The issues of reducing energy consumption are a priority for both individual producers and society as a whole. The costs for consumed energy affect not only the cost of a unit of finished products, but also carry a certain environmental burden [32, 33].

4.2.2. Initial provisions for the object of analysis

In the flexible automated process under study, robotic manipulators perform "point" operations to apply markings to structural elements of production. Tripod robots carry out transfer of volumetric structural elements onto a conveyor belt and their subsequent installation in specialized boxes. Several lines of interconnected robotic arms and robotic tripods operate in multiple. Local robot control systems solve problems of positioning, automatic control and logical control. Events occurring in flexible automated manufacture are, to a first approximation, Markov processes with discrete states and continuous time.

Taking into account the properties and characteristics of robots, conveyors, local and global networks, flows of structural elements, it is proposed to carry out optimization of electric consumption by parameterization of automatic control systems of electric drives.

Processes for searching optimal parameters of control systems are virtually solved using methods of mathematical, simulation modeling and planning of factor experiments on the hierarchical control system server using flexible automated production.

The hierarchical control system includes telecommunication networks, servers and specialized hardware and software and performs complex control of technological structural elements and solves system tasks of optimizing energy consumption of production process.

Mathematical models of large-scale industrial objects are built based on multi-mass calculation schemes [16, 28]. Using ratios and dependencies from [14, 16], a priori, as a function of the nominal parameters of electric drive objects, indicators of the properties and characteristics of large-scale industrial system elements can be calculated, for example: oscillation frequencies, resonant frequencies, damping coefficients, logarithmic decrements, frequencies of free undamped oscillations, resonant amplification coefficients, dynamic coefficients, electromagnetic and electromechanical time constants. For manipulator robots, the electric drive objects are 6 (six) DC motors. For tripod robots, the electric drive objects are an electromechanical rotary actuator and three servomotors.

For the conveyor plant, the electric drive objects are asynchronous electric drives with three-mass design schemes, taking into account the rigidity, dissipative losses and reduced clearances of gearbox gears, with a significant lag depending on the length of the carrier and idle conveyor belts.

In accordance with the technological process, flows of input structural elements (semi-finished products) are supplied for processing by elements of flexible automated production in stochastic sequences, the patterns of which are known but can change. Information on element flows is transferred over global and local telecommunication channels.

The quality criteria of the M&C large-scale industrial system depend on the size of structural elements, and the concept of "flexible automated production" assumes the existence of different batches of semi-finished products, for example, according to geometric characteristics or required technological processing operations. The latter conditions require storing information about batches of semi-finished products in the database of flexible automated production, and this information is the basis for individual control subsystems of the technological complex as a whole.

Processing operations by robotic manipulators and robotic tripods of each structural element and their groups, as well as movement of elements by conveyor installations are characterized as deterministic processes. This suggests that ranges of quality criteria for controlling robots and conveyors can be estimated, both by direct and integral estimates, as well as the stability conditions of a large-scale industrial system with their automatic control systems.

4.2.3. Algorithms and sources of power consumption minimization in large-scale industrial systems

In deterministic automatic control systems, it makes no sense to search for some unique methods and means for saving power consumption [34]. This is a technical problem of parametric optimization under different variants of electric drive and structure of automatic control systems. Some originality of this problem can be given in the robust formulation and, possibly, in the analysis of system of large-scale industrial objects as dynamic objects with incomplete information according to the theory of Professor N.V. Skibitskiy. [35].

The stochastic nature of semi-finished goods arrival creates the problem of estimating the ranges of possible energy consumption values in flexible manufacturing.

Assuming that the characteristics of the flow of semi-finished products to various lines of robotic manipulators are known and that these flows are characterized by known distribution laws (for example: normal, Poisson, etc.). There is a possibility that a defective structural element – a semi-finished product will enter the production line. This probability is stochastic and must be described by the equations of probability theory.

The selected types of electric drives and the structure of automatic control systems for flexible automated production are the means of ensuring minimization of electrical energy consumption, and the probabilities of a possible level of energy consumption are determined by the existing patterns of stochastic processes in flexible automated production and are the object of research in [29].

In [29], there is presented mathematical calculations of energy consumption minimization ranges for four operating modes of flexible automated production, including:

- Mode 1. Computer vision systems record the moments when a semi-finished product arrives for processing by a robotic manipulator, a tripod robot and a conveyor line. Information from sensors of computer vision system is transmitted via global and local telecommunication channels, placed in database and can be processed in the server of a hierarchical monitoring and control system. All processes are considered as deterministic. Then the range of energy consumption is within the boundaries between the maximum energy consumption (of a non-optimized system) and the sum of the minimum (optimized) consumption and energy costs for calculating the optimal operating mode of mechatronic devices;
- Mode 2. Due to the fact that semi-finished products arrive at the production line unevenly, the system is considered as a Markov process with discrete states and continuous time. The patterns corresponding to the flow of semi-finished products characterize it as the simplest (or stationary Poisson flow). In this case, the minimum energy consumption value will take into account the probability of a semi-finished product entering the production line at any time;
- Mode 3. The operation of flexible automated production using computer vision systems (i.e., as in mode 1) is influenced by the possible appearance of defects in elements of semi-finished products, which leads to skipping its processing. The operating time of the production line and the processing cycle of semi-finished products remain unchanged, but the total number of semi-finished products supplied for processing will decrease. Consequently, in the range of possible optimization according to the energy consumption criterion, the probability of the appearance of a defective semi-finished product is taken into account, which leads to a decrease in the limit of maximum (non-optimized) energy consumption;
- Mode 4. Functioning of flexible automated production is considered as a Markov process with an uneven flow of semi-finished products onto the line and the impact on the production line operation of the probable occurrence of defective semi-finished elements is taken into account (as in the mode 3).

4.3. Prerequisites for creating a universal methodology for effective management of power consumption in robotic production

The above theoretical provisions and algorithms for assessing power consumption, as well as structural and algorithmic proposals for implementing the processes of control, monitoring, regulation, automatic and automated control of an electric drive with parameterization of actuators according to the criteria for minimizing power consumption, suggest the possibility of creating a universal methodology invariant to the type of products being created in flexible automated production, and the laws of flows distribution of semi-finished products entering the production line.

It is fundamentally important to represent the production line as a "big" system with "big" data, in which the problem of uncertainty in the state of objects and systems is eliminated by concentrating in the database of a hierarchical system of control, monitoring and management of actually measured physical information by means of control and monitoring subsystems, forecasting physically unobservable information by subsystems of mathematical and simulation modeling [29].

The concept of "State of electrical complexes of aggregated installations of flexible automated production", which is defined as a set of information flows is described below:

- coordinates physically observed in real time are elements of the output signals that make up the vector Z(t);
- physically observable and unobservable state space coordinates are elements of the vector Y(t), which are obtained by simulation of mathematical models of electric drive elements and electric drive control systems;
- set of indicators of standard modes of electric drive elements, electric drive control systems;
- set of design data of electric drive, electric drive control system in flexible automated production;
- estimation of parameters of electric consumption by M&C electric drives for a fixed and declared period of time;
- estimation of resource and reliability of elements of the automated electric drive and large-scale system.

Characteristics of resource and reliability together with the evaluation of electric consumption analyzed above can be considered as an integral complex of technical state and operation of large-scale system elements, electric drive elements, electric drive control systems in flexible automated production. There are components in the information flow of states of electrical engineering complexes that allow us to take advantage of theoretical developments from [29, 34, 36] for estimating resource and reliability of automated electric drive elements.

In [7, 16], a methodology for assessing the durability of machine-building products with rotating shafts as a function of the ratios of deviations of minimum and maximum angular velocities and torques on the shafts for the analysed period was developed.

Coordinates Z(t), Y(t) – from the databases of complex of technical state and operation of large-scale objects of control and management allow, according to the method [16], to estimate the resource and reliability of the elements of the automated electric drive and, together with the estimation of electric consumption, to obtain the estimation of the integral complex of technical state and operation of the M&C large-scale system of the electric drive elements.

5. Research of M&C large-scale systems in the context of "INDUSTRY 4.0" technology

Effective research in real- and divided-time modes of the statics and dynamics of large-scale system components is possible using methods for conducting active and passive experiments [37] using specialized software and hardware LabVIEW and programming environment MatLAB-Simulink [18, 19] in the M&C server. The results of research are shown in [10, 28].

6. Training monitoring and control system of large-scale industrial objects in the context of "INDUSTRY 4.0" technology

The training process, more often understood as educational (process 1) for various categories of specialists, as well as students, undergraduates, graduate students and doctoral students, within the framework of the "Industry 4.0" technology is the process 2, aimed at adapting the M&C system of large-scale industrial objects using means and methods of artificial intelligence to the stochasticity of the environmental characteristics of large-scale systems and its elements.

In the process 1, significant results were achieved, including within the framework of the International Network Distance Learning Program "Synergy" [38].

Experience for realization of the process 2 is to be accumulated and there is important to create monitoring systems of state data about large-scale system components, storing and processing stochastic information flows, setting optimization intellectual tasks and their technical implementation [39].

7. Conclusion

This work "Automated robotic complexes in engineering, adjustment, production and education processes" solves the current scientific problem of creating a methodology, principles for constructing, research and improving of flexible automated production with robotic complexes driven by electric drives. Additionally, there are presented training projects for creating the M&C large-scale systems in the context of "Industry 4.0" technology within the framework of educational programs and research works of students and undergraduates majoring in "Automation and Control" and "Electric Power Engineering" based on the international educational project "Synergy". The research work results in the field of determining the optimization of an automated electric drive according to the criterion of energy consumption and calculations of resource characteristics and reliability of elements of automated production systems are shown.

8. References

[1] K. Shvab (2020) Chetvertaya industrialnaya revolyuciya (The fourth industrial revolution) https://www.youtube.com/watch?v=dCtuSThn9fo&t=2792s
[2] A.Zuyev (2018) Promyshlennaya revolyuciya. Industriya 4.0. (Industrial Revolution. Industry 4.0) https://www.youtube.com/watch?v=7um5warRsQs&feature= youtu.be
[3] Cifrovizaciya promyshlennosti. (2022) (Industrial digitalization) https://center2m.ru/tsifrovizatsiya-promishlenosti
[4] Tesic, S; Bajic, B; Cosic, I & Rikalovic, A (2021). Frugal innovations in Industry 4.0: The Identification of Key Indicators, Proceedings of the 32nd DAAAM International. Symposium, pp.0262-0269, B. Katalinic (Ed.),

Published by DAAAM International, ISBN 978-3-902734-33-4, ISSN1726-9679, Vienna, Austria, DOI: 10.2507/32nd.daaam.proceedings.037

[5] Polivka, M. & Dvorakova, L. (2021). The Current State of the Use of Selected Industry 4.0 Technologies in Manufacturing Companies, Proceedings of the 32nd DAAAM International Symposium, pp.0652-0659, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-33-4, ISSN1726-9679, Vienna, Austria DOI: 10.2507/32nd.daaam.proceedings.092

[6] Stazhkov S.M. (2021). International university network project "Synergy": 15 years of cooperation. Automation. Informatics, No. 1-2, p. 92-95, ISSN 1560-7305.

[7] Feshin B.N. (2011). Supervisory multi-connection control systems for electrical complexes of mining enterprises. Giga Trade, ISBN 978-601-879-107-3, Almaty.

[8] Tokhmetova K.M. (2021). Development of a remote-control system for the RTK "TRIPOD" in the FAM structure. Automation. Informatics, No. 1-2, p. 14-23, ISSN 1560-7305.

[9] Tokhmetova K.M., Kobylandy A.A., Baigul A.S., Suleimenova A.B. (2021). Development of a control system using the FESTO Mechatronic Line bench. Automation. Informatics, No. 1-2, p. 38-45, ISSN 1560-7305.

[10] Feshin B.N., Kalashnikova Ye.V. (2013). Monitoring system for FESTO servo and step electric drives. Automation. Informatics, No. 2 (33), p. 71-75, ISSN 1560-7305.

[11] http://mexatronica-pro.com. Matronika-Pro RPC. MSV-02 - Adjustment kit for a developer of electric motor control systems. Technical description. Tomsk. - 2014.- p.5.

[12] http://mexatronica-pro.com. Matronika-Pro RPC. MexBIOS Development Studio. Getting started - a guide for new users. Description of integrated environment. Tomsk. - 2014.- p.50.

[13] Wang, D. L.; Zeng, X. T.; Wang, G. F. & Li, R. (2021) Stability of a face guard in a large mining height working face, International Journal of Simulation Modelling, 20 (2021), pp. 547-558, Publisher: DAAAM International Vienna, DOI 10.2507/IJSIMM20-3-572, ISSN:1726-4529

[14] Video lecture, Feshin B.N. Joint inter-university course of the network distance learning program Synergy "Intelligent Control Systems" for master's students majoring in "Automation and Control", "Electric Power Engineering". http://y2u.be/uwz_hM3nGnE

[15] Avdeev L.A., Kostin M.I. (2017). Karaganda Scientific Research Coal Institute (structural transformations and achievements in the field of automation of production processes). Automation. Computer science, 2(41), pp.140-148, ISSN: 1560-7305

[16] Feshin B.N. (2018). Multi-connected supervisory control systems for coal-mining machines: Monograph. Karaganda: KSTU. ISBN 978-601-315-470-1.

[17] Feshin, B.N., Shpakova, L.G., Tokhmetova, K.M. (2023). Hierarchical Management System of the Coal-Winning Complex. Lecture Notes in Mechanical Engineering, Publisher: Springer Nature, pp. 220–230, ISSN: 2195-4356, DOI: 10.1007/978-3-031-38126-3_23

[18] Dyakonov V.P. (2004). MATLAB 6/6.1/6.5/ + SIMULINK 4/5®. Application basics [Text]: complete user guide, SOLON-Press, ISBN 5-98003-007-7, Moscow.

[19] Terekhov V.B. (2022). Computer modeling of DC and AC electric drive systems in Simulink: textbook. Yurait Publishing House, ISBN 978-5-5-534-06858-0, Moscow.

[20] Breido I.V., Zyuzev, Feshin B.N. (2016). New technologies for setting up and adjustment automated electric drives. Automation. Informatics, No. 2 (39), p. 72-84, ISSN 1560-7305.

[21] Basharin A.V., Novikov V.A., Sokolovsky G.G. (1982). Control of electric drives: textbook for universities. L.: Energoizdat, - p. 392.

[22] Belov M.P., Zementov O.I., Kozyaruk A.Ye., Kozlova L.P., Novikov V.A., Savva S.V., Chernigov L.M., Gorokhov S.G., Tatarintsev N.I. Engineering of electric drives and automation systems: textbook. M.: Academy Publishing center, ISBN 5-7695-2448-0, Moscow.

[23] Basharin A.V., Postnikov Y.V. (1990). Examples of calculation of the automated electric drive on the computer: [Textbook for universities majoring in "Electric drive and automation of industrial plants and technological complexes"]. L.: Energoatomizdat. Leningrad Branch, ISBN 5-283-04468-8, St. Petersburg.

[24] Zyuzev A.M., Mudrov M.V., Nesterov K.Ye. (2014). FPGA-simulator of real-time AC electric drive. Energy. Innovative directions in the energy sector. Cals technologies in the energy sector, №1, pp. 229-238

[25] Nesterov K.E., Mudrov M.V., Zelentsov V.I. (2016), Simulator of the shunting locomotive's electric drive 2nd international conference on industrial engineering, applications and manufacturing, 6 2016 Chelyabinsk, 19–20 мая 2016 года, Chelyabinsk, doi: 10.1109/icieam.2016.7911523

[26] Zyuzev A.M., Bubnov M.V., Mudrov M.V. Simulator of electric drive of the rod deep-well pumping unit. II International Scientific and Technical Conference "Prom-Engineering". 2016. – p.4.

[27] Feshin B.N., Shpakova L.G., Tokhmetova K.M. (2018). Hierarchical control and monitoring systems of large automated technological complexes. University works, No. 2, p. 114-120, ISSN 1609-1825.

[28] Kalashnikova Y., Feshin B. and Peshko M. (2021). Monitoring of High-Voltage Electric Drives of Pumping Units of Heat Supply Complexes of Megacities. XVIII International Scientific Technical Conference Alternating Current Electric Drives ACED, May 24-27, 2021, Ekaterinburg, Russia, pp. 1-5, ISBN 978-1-6654-1248-3, DOI: 10.1109/ACED50605.2021.9462310.

[29] Feshin B.N., Shpakova L.G., Tokhmetova K.M. (2019). Algorithms of energy saving in flexible automated productions (part 1). University works, No.3, p.145-147, ISSN 1609-1825.
[30] B.N. Feshin, K.M. Tokhmetova, Ye.V. Kalashnikova and L.G. Shpakova. (2023) Optimization of power consumption and equipment operating life in large mechatronic and robotic facilities. EAI Endorsed Transactions on Energy Web, unpublished.
[31] Moldavskiy L.A., Finkelshtein E.L., Verklov B.A. (1981). Types of damage and durability of mining machine transmissions. Moscow: Nedra.
[32] P. Waide, C. Brunner, (2011) Energy-efficiency policy opportunities for electric motor driven systems. Int. Energy Agency, p.132. ISSN: 2079-2581 https://doi.org/10.1787/20792581.
[33] Jollands, N., Waide, P., Ellis, M., Onoda, T., Laustsen, J., Tanaka, K., … Meier, A., (2010) The 25 IEA energy efficiency policy recommendations to the G8 Gleneagles Plan of Action. Energy Policy, Volume 38, Issue 11, pp. 6409–6418. doi.org/10.1016/j.enpol.2009.11.090.
[34] Feshin B.N., Shpakova L.G., Tokhmetova K.M. (2019). Optimal robots control in flexible automated manufacturing. University works, No. 1, p. 145-148, ISSN 1609-1825.
[35] Skibitskiy N.V. (2005) Interval methods and problems of constructing models of objects and control processes: Dissertation of Doctor of Engineering Sciences: 05.13.01. Department of Management and Informatics, National Research University Moscow Energy Institute, Moscow, Russia.
[36] Feshin B.N., Shpakova L.G., Tokhmetova K.M., Kalashnikova E.V. (2021). Optimization of power consumption and service life of machines in large production complexes of mechatronic-robotic type. Abstracts of the XI international scientific and technical Internet conference for young scientists "Automation, mechatronics, information technologies" (AMIT), May 2021, Omsk, ISBN 978-5-8149-3306-5, p. 37-40.
[37] Breido I.V., Feshin B.N. (2003). Simulation modeling and parametric optimization of automated electric drives. Ministry of Education and Science of RK, Karaganda State Technical University, ISBN 9965-606-56-0, Karaganda.
[38] Breido I.V., Yeliseyev A.S., Katalinich B., Kramar V.A., Pashkov E.V., Stazhkov S.M., Feshin B.N., Homchenko V.G., Shtol V. (2015). International university network project "Synergy": modern possibilities of combining and using educational resources of engineering universities in cooperation with the leading European concern FESTO. Automatics. Informatics, No. 1, P. 16-20, ISSN 1560-7305.
[39] Jones M.T. (2011). Artificial intelligence programming in applications. DMK Press, ISBN 978-5-94074-746-8, Moscow.