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Satbayev University

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РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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THE CONTROL OF FLEXIBLE AUTOMATED PRODUCTION OF THE SCRAPER CONVEYERS

Abstract. The analysis of possible energy saving in in the technological process of production of elements of scraper conveyors containing flexible automated production is given. It consists of complex subordinate aggregate installations consisting of conveyor lines, robot manipulators and tripods.

The studied technological processes and control systems for electric drives of actuators are multi-connected, distributed in space, stochastic and multidimensional in the number of control and monitoring coordinates. It is proposed a methodology of reducing energy consumption of actuators by means of physical-virtual modeling and parameterization based on estimates of energy costs, by means of planning factor experiments, steep ascending in the anti-gradient direction of integral quadratic estimates of the control system, which are proportional to the costs of electricity in transient modes of actuators. The methodology, in comparison with the well-known optimization methods, is invariant to the type of products developed in flexible automated production, to the laws of distribution of the semi-finished products flows entering the production line, and is focused on predicting the boundaries of the saved energy and the life of the electromechanical equipment and improving reliability of electric drive control systems operation as a part of industrial complexes.

The uniqueness of the method consists in applicability of the developed algorithm of evaluating energy savings and optimizing technological processes according to the criterion of energy consumption in real time in the conditions of the probabilistic situation of input parameters, regardless of the selected method of setting the optimal parameters of production line facilities.

Key words: power consumption, electric drive, robotic production, control system, scraper conveyor, methodology, criterion, optimization, parameterization, structure, forecast, resource.

Introduction. Electric motors and systems driven by electric drives are the largest energy consumers (up to 46% of the total world consumption). It is expected that by 2030, without comprehensive and effective measures in the field of energy efficiency, energy consumption by electric motors will increase to 13,360 TWh per year, CO^2 emissions from energy production for their provision will rise to 8,570 tons per year, and consumer spending for electricity used in the systems with electric drives, will increase up to 900 billion US dollars [1], p. 11]. Due to the undeniable importance of energy consumption by electric drives, including robotics in the industrial sector, measures to improve energy efficiency in industry have a positive potential in environmental, economic and social aspects [2]. In this paper it is studied a multiply connected, multidimensional, distributed in space, stochastic, “large” in a multitude of coordinates, control, object of monitoring and controlling representing a complex technological process (TP), which is a flexible automated production (FAP) in which interrelated work operations under semi-finished products (SF) performed by robotic arms, robotic tripods and conveyors. In the materials of subsequent studies, we will call this object as "a large object, mechatronic and robotic", LOMR [3],[4].

Examples of the technological processes in the mining industry are the FAP of mass production of steel gratings for scraper conveyors, rollers and roller supports of belt conveyors, elements of hydraulic mechanized supports. In the automotive industry, this is the FAP of manufacturing complex structural elements of bodies and subsequent car Assembly processes. In mass light, food and pharmaceutical production, these are processes related to point contact operations (for example, spot welding and/or marking, milling and drilling, stamping and screw fastening), with continuous and discrete movement of parts, partially finished semi-finished products and finished products. Scraper conveyors are constructed from strips of metal by cutting, welding, drilling, milling, stamping, marking, and manipulation in space. One of the criteria of the LOMR efficiency is minimization of electrical consumption per unit of the FAP finished products. This problem is the subject and purpose of research in this paper.

At the same time, the technology of electric energy consumption minimization proposed in this paper is based on the possibility of using global and local networks to transfer physically received information from the LOMR to the server of the hierarchical monitoring and control system (MC HCS) of the FAP, in order to analyze the proximity of the LOMR operation modes to the reference values of power consumption, with the subsequent development in the ICS of MC algorithms that allow finding the state of the LOMR and the LOMR control systems (by mathematical and simulation in a virtual server environment) that improve power consumption, and then changing the LOMR operating modes directly by transmitting new values of the control device settings (optimal settings: tuning parameters) of the LOMR control systems.

I. The directions of research in the field of energy savings and energy consumptions efficiency assessment. The optimization methods, in their calculations do not take into account the laws of probability associated with stochasticity of real processes. This leads to the fact that any results of the above studies at real plants will correspond to experimental ones with only a certain degree of probability.

This paper presents methods of monitoring and analyzing energy consumption, which allow to develop mathematical models for estimating parameters in order to further optimization of energy consumption and, consequently, minimization of production costs, taking into account stochasticity of the processed flows. The developed methodology makes it possible to design new and to modernize the existing production lines according to the criteria of energy efficiency and to minimize energy consumption in the long term.

II. Methodology of assessing energy consumption reducing in flexible automated production.

2.1. Objects of the system that affect energy saving in the FAP conditions. Considering the properties and characteristics of robots, conveyors, local and global networks, flows of structural elements, semi-finished products, it is proposed to optimize power consumption by parameterizing automatic drive control systems. The processes of searching for the optimal parameters of control systems are solved virtually, using the mathematical and simulation methods and planning of factor experiments on the server of the FAP hierarchical control system (HCS).

The FAP HCS, including telecommunication networks, servers and specialized software and hardware, provides integrated management of technological structural elements and solves systemic problems of optimizing FAP power consumption. Input semi-finished product flows are received for processing by the LOMR elements in stochastic sequences, the patterns of which are known but can change. The information of the SF flows is transmitted through the global and local telecommunication channels. The treatment processes of each semi-finished product and groups of SF robots, manipulators, robots, tripods and the movement of SF conveyor plants are characterized as deterministic processes. This suggests that ranges of criteria for controlling robots and conveyors can be calculated both by direct and integral estimations, as well as stability conditions for the LOMR elements with their automatic control systems.

2.2. The Sources of minimizing energy consumption in the FAP. In deterministic automatic control systems, it makes no sense to look for some unique methods and tools of saving energy consumption [5]. This is a technical task of parametric optimization with various options for the electric drive and the structure of the ATS. The selected types of electric drives and the structure of the ATS in the FAP are a means of minimizing electric energy consumption, and the probabilities of a possible level of energy consumption are determined by the existing laws of stochastic processes in the FAP and are the aim of research in this scientific work.

2.3. Algorithms for minimizing power consumption by LOMR control systems. The stochastic nature of receiving semi-finished products creates a problem of estimating the ranges of possible energy values in the FAP.

Supposing that characteristics of the semi-finished products flows to various lines of robotic manipulators are known, and that these flows are characterized by well-known distribution laws (for example: normal, Poisson, etc.).

The enlarged algorithm of minimizing power consumption in flexible automated production using the LOMR automated electric drive, targeted parametric optimization of the LOMR ATS and under the supervision of a hierarchical control, monitoring and control system (MC HCS) of the FAP is presented below.

The information of the semi-finished products flows is transmitted through global and local channels of telecommunication, is placed in the database and can be processed on the MC HCS server. It is assumed that the distribution law of the semi-finished product flow arriving at the input R_1 of the robotic arm is known. The moment of receiving the first semi-finished product is fixed and the SF processing program is launched by means of the robot manipulator. The parameters and structure of the automated electric drive are taken from the FAP database, where they were previously located. Each SF treatment process is controlled by the monitoring system in the form of recording the coordinates of automated robotic electric drives and the conveyor in the FAP database. The times of the SF arrival for processing by the tripod robot k_1 and its subsequent movement by the conveyor Q_1 are recorded and placed in the database of the FAP MC HCS server. Using the coordinate records, the energy costs of the electric drives for each robot and conveyor work session can be calculated. The ranges of permissible energy costs per finished product unit for various drive options and local LOMR control structures are placed in the database in the MC HCS server. In the control period of the LOMR and FAP operation, the possible electric costs are calculated and compared with the permissible ranges of energy costs. The comparison results are used to carry out virtual experiments, the purpose of which is to select (by means of simulation according to the plans of optimal factor experiments and steep ascent in the direction of the anti-gradient of the integral quadratic estimation of automatic control systems [6], [7], [8] promising options for the LOMR control systems structures and parameters in the FAP MC HCS. Permissible changes in the structure and parameters of automated electric drives and the LOMR ATS from the MC HCS are introduced and technological operations are carried out in the next period of the FAP operation.

3.4. Stochastic characteristics of the semi-finished products flow effect on power consumption in the FAP. In figure 1 the analyzed flexible automated production is considered in the first approximation as a Markov process with discrete states and continuous time. According to [9], p. 182] the processes (objects and systems) with discrete states and continuous in time have the following property: "...For each moment of time t_0 the probability of any state of the system in the future (for $t > t_0$) depends only on its current state (at $t = t_0$) and does not depend on when and how the system came into this state (that is, how the process developed in the past)".

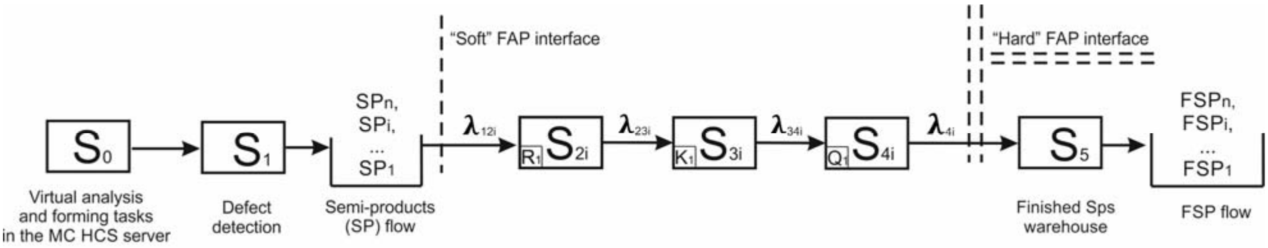

Figure 1 – Flexible automated production as a Markov process:
R_1 – robot-manipulator; K_1 – robot-tripod; Q_1 – conveyor, $S_{2i} \longrightarrow R_1 \cdot SF_i$; $S_{3i} \longrightarrow k_i R_1 \cdot SF_i$; $S4_i \longrightarrow Q_1 k_1 R_1 \cdot SF_i$

The S_0 event is related to the quality control processes taking place in the MC HCS, and the preparation of the SF flow for subsequent deformation in the LOMR. The detection of a defective SF in the flow as a Markov process, as well as its removal from the processing line, is event S_1. The appearance of a defective SF can affect the SF flow and then remove it from the circuit (event S_1). Therefore, the state of the SFi obtained for processing by the manipulator R_1 is controversial and is further characterized as a probabilistic phenomenon with the estimate: $0 \le \lambda_{12i} \le 1$. The information of the design, geometric and mass characteristics of the SF, as well as time stamps and periods of the movement of the SF between the soft FAP boundary and the R1 robotic arm, is important. This is associated with the adjustment of the control systems R_1, and subsequently the control systems of the robot tripod k_1 and the conveyor Q_1, according to the direct and integral quality criteria.

2.4. Analyzing the LOMR into FAP transient processes. The LOMR technological process consists in the performing by the R_1 robot of spot welding on SF_i, gluing a label on the SF_i by the robot-tripod and moving by the SF_i conveyor. The settings of the control systems of electric drives R_1, k_1 and Q_1 are the only means of affecting the dynamic processes associated with the LOMR. In the enlarged algorithm, technological operations are promptly performed and information is transmitted via telecommunication networks to the MC HCS [4], [10]. The actions for the parametric optimization of the LOMR control systems are performed virtually in the MC HCS by simulation using the technology of planning special factor experiments in the settings of various control systems for the LOMR electric drives. Figure 2 provides an interpretation of the processes of minimizing power consumption by means of the LOMR electric drive control systems.

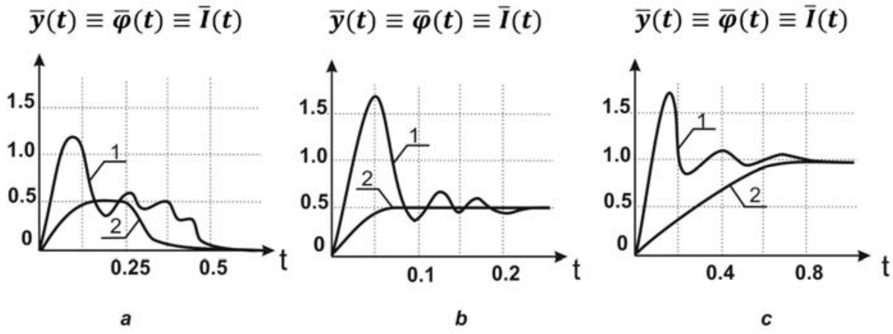

Figure 2 – Transit processes in the LOMR ACS. Transit processes execution units in control systems:
a – of the robot manipulator; b – of the robot tripod; c – of the conveyor.
Trajectories of movement of executive bodies: 1 - tuning, 2 – optimal

An estimate of the boundaries of possible power consumption can be made on the assumption that there is a direct relationship between the quality of dynamic processes, estimated by the time dependences of the coordinates R_1, k_1, Q_1, and the cost of electricity for moving actuators, which are proportional to the square of the deviations of the analyzed coordinates from the reference values.

The situation when the motor of the R_1 robot's gripper is positioned geographically by the coordinate of spot welding (figure 2a, graph 1). Evaluation of the qualitative characteristics of graph 1 (obviously, they are unsatisfactory) starts the process of parametric optimization, in accordance with paragraphs 9 and 10 of Section 2.3. The result of the decision on the next cycle of the R1 operation is graph 2 of the grip movement.

The situations are similarly interpreted when the k_1 robot tripod sticks a label on the SF_i located on the moving traction belt of the Q_1 conveyor. Then, virtually in accordance with paragraphs 9 and 10, there is made a search for the optimal settings, characterized by graphs 2 (figure 2, b and c).

III. The methodology of assessing the boundaries of the probable energy consumption of energy conservation in the FAP. Supposing that the process equipment R_1, k_1 and Q_1 is installed in the FAP (look at figure 1). In modern reality, the state of the means of collecting and processing information, various implementations of monitoring and control systems for technological units R_1, k_1 and Q_1 are possible. Next, we consider several options for operation of the FAP and R_1, k_1 and Q_1 in order to assess the minimum energy consumption ranges in the FAP, including:

FAP1. Computer vision systems (CVS) record the moments of receiving SFi for processing R_1, k_1 and Q_1. The CVS information is transmitted via global and local telecommunication channels, placed in a database and can be processed in the MC HCS server. All processes in the FAP are considered deterministic;

FAP2. The FAP in figure 1 is considered as a Markov process with discrete states and continuous time;

FAP3. The operation of the FAP with the CVS (i.e., as in FAP1) is affected by the possible occurrence of defects in the elements of the SF;

FAP4. The FAP functioning is considered as a Markov process (as in FAP2) and the impact on the work of the FAP is considered to be the occurrence of defective SFs (as in FAP3).

3.1. Analyzing possible energy consumption reducing in FAP1. The number of operations in AAP 1 for the conversion of Si, where i = $\overline{1,n}$, using R_1, k_1 and Q_1 is 3n. let's suppose that the energy costs for translating the EDO are proportional to the areas of deviations of the transients from the given values of the adjustable coordinates in figure 2, and the settings of the ATS, in order to move from processes characterized by temporary, not optimal dependences 1 (figure 2) require at least m virtual experiments in the MC HCS (m = $m_{Вy1}$+$m_{Вy2}$+$m_{Вy3}$, where $m_{Вy1}$, $m_{Вy2}$, $m_{Вy3}$ is the number of virtual experiments with models and control systems of the R_1, k_1 and Q_1 installations. For example, for the controllers with two tuning parameters, the planning matrix requires no less than (2^2+1) experiments [11], coefficient MK [[Energy units]/[$\overline{y}$] [Reg. values]] and supposing that in the first approximation of the area S_{1y} (for R_1), S_{2y} (for k_1) and S_{3y} (for Q_1) the deviations of transients from the given values of the controlled coordinates of type 2 (see figure 2) are no less than SK-times smaller than the corresponding areas of processes 1 in figure 2 (for example, when SK = 0.5, the area of type 2 is two times smaller than the area of type 1).

Taking into account the introduced notations and assumptions, we determine the energy indicators of FAP1.

1. The total energy consumption for carrying out technological operations on R_1, k_1 and Q_1 with the initial (not optimal) parameters of the regulators:

$$\mathrm{Q_{max}} = \mathrm{MK} * (S_{1y} + S_{2y} + S_{3y}) \cdot (3\mathrm{n}). \quad (1)$$

2. Power consumption for the R_1, k_1, Q_1 EDO ATS tuning:

$$\mathrm{Q_{conf}} = \mathrm{MK} \cdot (S_{1y} + S_{2y} + S_{3y}) \cdot (m). \quad (2)$$

3. Power consumption after the R_1, k_1, Q_1 EDO ATS tuning:

$$\mathrm{Q_{min}} = \mathrm{SK} \cdot \mathrm{MK} \cdot (S_{1y} + S_{2y} + S_{3y}) \cdot (3\mathrm{n} - \mathrm{m}). \quad (3)$$

4. The value of maximally possible energy saving:

$$\Delta Q_{max} = Q_{max} - Q_{min}. \quad (4)$$

5. The range of possible energy saving:

$$Q_{conf} \leq \Delta Q \leq \Delta Q_{max}. \quad (5)$$

3.2. Analysis of possible reducing of energy consumption of FAP2. The following assumptions might be done regarding to FAP2 (T – the period of operation): the SF_i flow entering for processing at R_1 is a Markov process; the time cycle of processing SF_i on R_1, k_1 and Q_1 is a known value equal to t_{sf}; SF_i processing ends when the SF_i arrives beyond the "hard" FAP boundary; processing the SF_{i+1} of the semi-finished product begins after the end of the t_{sf} period (relative to the beginning of the processing of SF_i) and subject to the appearance of SF_{i+1} at the "soft" FAP interface (figure 1); the conditions, designations and parameters previously adopted for FAP1 are also valid in the case under consideration. These assumptions simplifying the analysis process allow obtaining for FAP2 conditions of type (5) with a probabilistic characteristic of the left and right boundaries. It is obvious that in the LOMR monitoring and control system, quantity counting devices processed at a specific point in the SF_i time will be required. It is technically not difficult to develop a discrete system that controls the passage time of SF_i through R_1, k_1, Q_1, fixing the duration of the operation t_{jsf} and its cycle number j_{isf}. At the moment of the end of the FAP2 T operation period, the number of processed SF_i will be equal to $N_{jsf} = T/t_{jsf}$. Then Q_{min} is calculated from:

$$\mathrm{Q\ _{min}} = \mathrm{SK} \cdot \mathrm{MK} \cdot (S_{1y} + S_{2y} + S_{3y}) \cdot (3N_{jsf} - \mathrm{m}), \quad (6)$$

and Q_{max} as follows:

$$\mathrm{Q_{max}} = \mathrm{MK} * (S_{1y} + S_{2y} + S_{3y}) * (3N_{jsf}) \quad (7)$$

For FAP2 relations (4) and (5) are valid in the probabilistic setting, due to the fact that the SF_i flow at the input of FAP2 is a Markov process. Suppose that the laws corresponding to the flow of SF_i characterize it as follows: "...stationary, without aftereffect, ordinary. Such a flow is called the simplest one (... or stationary Poisson flow)" [9], p.202] that plays the same role in the queuing theory as the normal distribution of random variables in the probability theory [12], p.11]. Then, we assume that the intensity S_{sfi} as the average number of possible SF_i receiving at the input of the FAP is a constant value: S_{sfi} = const, the probability of receiving semi-finished products SF_i in the interval of time t in the amount of k will be calculated by the Poisson formula [9], [12]:

$$P_k(t) = \frac{(S_{sfi} \cdot t)^k}{k!} \cdot e^{-(S_{sfi} \cdot t)}. \quad (8)$$

Using an algorithm for calculating the probabilistic characteristics of an element of the simplest flow of events with intensity S_{sfi}=const [9] to estimate the time interval tt_{sfi} between the occurrence of the SF_i event on the "soft" FAP interface and the next SF_{i+1} event on the time axis T.

The distribution function determines the probability of the fact that the tt_{sfi} value will become smaller than the time axis T: F(t) = (tt_{sfi} < T).

Supposing that the SF_i arrives at the soft boundary of the FAP at time tt_0. The possible time of receiving the next semi-finished product can occur during the TT period. It is necessary to determine the probability that the interval tt_{sfi}, through which SF_{i+1} will be smaller than TT. For this, it is necessary that at least one flow event falls on a section of the TT length adjacent to the point tt_0. The calculation of the probability of this F(t) is possible through the probability of the opposite event (i.e., to assume that no flow event will fall on the TT section) [8, p. 204]:

$$F(t) = (1 - P_0). \quad (9)$$

Here the P_0 probability is found by formula (8) at k = 0:

$$P_0(t) = \frac{(S_{sfi} \cdot t)^0}{0!} e^{-(S_{sfi} \cdot t)} = e^{-S_{sfi} \cdot t}, \quad (10)$$

then the function of tt_{sfi} distribution will be:

$$F(t) = 1 - e^{-(S_{sfi} \cdot t)}, (t > 0), \quad (11)$$

and the density of the random value tt_{sfi} distribution will be:

$$f(t) = S_{sfi}\, e^{-S_{sfi} \cdot t}, (t > 0). \quad (12)$$

The tt_{sfi} with the density of distribution (12) is described by the exponential law of distribution. At this mathematical expectation and the mean quadratic deflection of the tt_{sfi} for the conditions considered are equal to each other and inverse to the S_{sfi} parameter [[9], pp.204, 205]. For FAP2 expression "the element of probability of the event occurrence" is also important [[9]]. For the period of tuning FAP2 SF_i, (i.e. at i=1, …, m) and the last in the flow semi-finished product in FAP2, SF_i, (i.e. at i= N_{jsf}) "the element of probability of the event occurrence'' is calculated by formula (8) and defines the probability of successful tuning the EDO ACS R_1, k_1, Q_1 (for k = m):

$$P_k(t) = \frac{(S_{sfi} \cdot t)^m}{m!} \cdot e^{-S_{sfi} \cdot t} \quad (13)$$

i.e. it is the probability of the "left" range of power saving (5) for FAP2, and for the "right" range (5), when k = N_{jsf}, the probability will be equal to:

$$P_k(t) = \frac{(S_{sfi} \cdot t)^{N_{jsf}}}{N_{jsf}!} \cdot e^{-S_{sfi} \cdot t}. \quad (14)$$

3.3. Analyzing possible power consumption reducing in FAP3. The structure of FAP3 will be considered as a closed collection of series-connected devices and virtual information packets. Supposing that the production line receives SFs, among which there are defective items, which lead to the omission of its processing. To increase the reliability and efficiency of this process, it is necessary to use formal mathematical and simulation methods [13] and take into account the probabilistic nature of the appearance of a defective SF on the processing line. The time T of the FAP operation and the processing cycle of the SF, - $tj_{пф}$ remain unchanged, but the total number of SFs supplied to the processing will decrease and will be equal to $n_{деф}$<n, respectively, the number of processed semi-finished products at the end of T will be Nn_{def}< Nj_{sfi}. Then, when evaluating the energy savings in formulas (6) and (7), Nj_{sfi} should be replaced by Nn_{def}:

$$Q_{\min} = SK \cdot MK \cdot (S_{1y} + S_{2y} + S_{3y}) \cdot (3Nn_{def} - m), \quad (15)$$

$$Q_{\max} = MK \cdot (S_{1y} + S_{2y} + S_{3y}) \cdot (3Nn_{def}). \quad (16)$$

The probability of operability of a system consisting of series-connected devices is equal to the product of the probabilities of each device, and the failure (inoperability) of one device makes the entire system inoperative [14].

We characterize the magnitude of the energy savings ΔQ in FAP3 as a random value equal to the difference between the actual value ΔQ_{max} and the estimate $\Delta \bar{Q}_{max}$. Then, with probability λ, the ΔQ_{max}value is determined in a certain confidence interval I_λ:

$$P\ ((\Delta Q_{max} - \Delta \bar{Q}_{max}) < \mathcal{E}_e) \leq \lambda, \quad (17)$$

where $\Delta \bar{Q}_{max}$ is an unbiased estimate ΔQ_{max}, determined as mathematical expectation M (ΔQ_{max}) = = $\Delta \bar{Q}_{max}$.

The range of possible ΔQ_{max}, values when replacing it by $\Delta \bar{Q}_{max}$, will be $\pm\varepsilon_e$ and (17) can be presented in the form [12]:

$$P\ \{(\Delta Q_{max} - \mathcal{E}_e)(\Delta Q_{max} + \mathcal{E}_e)\} = \lambda. \quad (18)$$

Equality (18) means that the ΔQ_{max} value with probability λ falls into the interval

$$I_\lambda = \{(\Delta Q_{max} - \mathcal{E}_e)(\Delta Q_{max} + \mathcal{E}_e)\}. \quad (19)$$

Here, the ΔQ_{max} value is not random but the I_λ interval is random. The interval I_λ position is random and is defined by the $\Delta \bar{Q}_{max}$ center. The interval length is also random and is equal to $2\cdot\varepsilon_e$. From here it follows that with observing condition (17), the energy saving value ΔQ_{max} in the $2\cdot\varepsilon_e$ interval can be equal to 0.607ΔQ. Here the ΔQ_{max}= 0.607Δ value will depend on the S_1 event that reflects the state of the sequence closed structure of FAP3, and the probabilistic assessment of this state can change periodically in the range of 0≤ λ≤ 1 (in figure 1 λ_{12i} = λ).

3.4 Analyzing the probability of power consumption reducing in FAP4. Possible results of decreasing power consumption in FAP2 and FAP3 do not imply estimates other than those already obtained above. In this case, the only new control will be switching the FAP state from the FAP2 option to FAP3 and vice versa.

Conclusion. The above theoretical principles and algorithms for evaluating power consumption, as well as structural and algorithmic proposals for the implementation of control, monitoring, regulation, automatic and automated control processes with parameterization of control systems for executive devices according to criteria for minimizing power consumption, suggest the possibility of developing a universal methodology that is invariant to the type of products developed in the FAP and the laws of distribution of the semi-finished products flows entering the FAP. In the work an urgent scientific problem of developing a methodology of building principles, studying and improving of flexible automated productions with aggregated robotic installations driven by electric drives of has been solved.

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СКРЕПЕРЛІ КОНВЕЙЕР ӨНДІРІСІНІҢ ИКЕМДІ АВТОМАТТАНДЫРЫЛҒАН ӨНДІРІСІН БАСҚАРУ

Аннотация. Икемді автоматтандырылған өндіріс құрамына кіретін скреперлі конвейерлер элементтерін (бөлшектерін) өндірудің технологиялық процесінде энергияны үнемдеудің ықтимал талдауы келтірілген. Бұл өндірістің құрамына күрделі бағынышты агрегатталған қондырғылар, атап айтқанда конвейерлік желілер,

робот-манипуляторлар және триподтар кіреді. Зерттеліп отырған технологиялық процестер мен атқарушы құрылғылардың электр жетегін басқару жүйелері көпбайланысты, кеңістікте таратылған және басқару мен бақылау координаталар саны бойынша көпөлшемді және стохастикалық болып табылады. Атқарушы құрылғылардың ауыспалы режимдерінде электр энергия шығындарына пропорционалды болып табылатын факторлы эксперименттер мен басқару жүйесінің интегралды квадраттық антиградиентінің бағытына тік көтерілуді жоспарлау негізінде физикалық-виртуалды модельдеу мен электр энергиясының шығындарын бағалауға негізделген параметризация құралдары арқылы электр энергиясын тұтынуды азайту әдісі ұсынылған. Ұсынылып отырған әдіс белгілі оңтайландыру әдістерімен салыстырғанда, икемді автоматтандырылған өндірісте жасалған өнім түріне, өндіріс желісіне түсетін жартылай фабрикаттар ағындарының таралу заңдылықтарына байланысты өзгермейді және электрмеханикалық жабдықтың үнемделген энергиясының шекаралығын және тозу мерзімдерін болжауға, сонымен қатар өндірістік кешендердің құрамына кіретін электр жетектерін басқару жүйелерінің жұмысының сенімділігін арттыруа бағытталған.

Ұсынылып отырған әдістің бірегейлігі - жасалынған (мақалада ұсынылып отырған) алгоритмді технологиялық процестердің кіріс параметрлерінің ықтималдық сипаты жағдайында нақты уақыт режимінде энергияны тұтыну критерийі бойынша энергия үнемдеуді бағалау және технологиялық процестерді оңтайландыру үшін қолданылуында жатыр.

Түйін сөздер: электр энергиясын тұтыну, электр жетегі, робот өндірісі, басқару жүйесі, скреперлі конвейер, әдістеме, критерий, оңтайландыру, параметризация, құрылым, болжам, ресурс.

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УПРАВЛЕНИЕ ГИБКИМ АВТОМАТИЗИРОВАННЫМ ПРОИЗВОДСТВОМ ИЗГОТОВЛЕНИЯ СКРЕБКОВЫХ КОНВЕЙЕРОВ

Аннотация. Приведен анализ возможного энергосбережения в технологическом процессе производства элементов (деталей) скребковых конвейеров, содержащем гибкое автоматизированное производство. В его состав входят сложноподчинённые агрегатированные установки из конвейерных линий, роботов-манипуляторов и триподов. Исследуемые технологические процессы и системы управления электроприводами исполнительных устройств являются многосвязными, распределенными в пространстве, стохастическими и многомерными по количеству координат контроля, управления и мониторинга. Предлагается методика снижения потребления электроэнергии исполнительными устройствами средствами физико-виртуального моделирования и параметрирования на основе оценок затрат электроэнергии, путем планирования факторных экспериментов, крутого восхождения в направлении антиградиента интегральных квадратичных оценок системы управления, пропорциональных затратам электроэнергии в переходных режимах исполнительных устройств. Предложенная методика, в сравнении с известными методами оптимизации, инвариантна к типу изделий создаваемых в гибком автоматизированном производстве, законам распределения потоков полуфабрикатов, поступающих на производственную линию, и ориентирована на прогнозирование границ сэкономленной энергии, износного ресурса электромеханического оборудования и повышения надежности эксплуатации систем управления электроприводами в составе промышленных комплексов.

Уникальность предложенного метода заключается в применимости разработанного алгоритма для оценки экономии электроэнергии и оптимизации технологических процессов по критерию энергопотребления в режиме реального времени в условиях вероятностного характера входных параметров технологических процессов.

Ключевые слова: электропотребление, электропривод, робототизированное производство, система управления, скребковый конвейер, методика, критерий, оптимизация, параметрирование, структура, прогноз, ресурс.

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