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DEVELOPMENT OF THE METHOD OF QUASI-OPTIMAL ROBUST CONTROL FOR PERIODIC OPERATIONAL PROCESSES

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Пошук супремуму оптимальної траєкторії управління практично недосяжний в реальних умовах. Це пов'язано з великою кількістю ступенів свободи керованої системи, коливанням попиту, вхідних і вихідних цін, істотною нелінійністю внутрішньосистемних процесів. Виходом в такій ситуації може бути розробка робастних методів квазіоптимального управління. Пропонований підхід заснований на встановленні взаємозв'язку управління перетворювальної системи з поточним рівнем виробничих запасів

Ключові слова: оптимізація пов'язаних систем, квазіоптимальний управління, робастна оптимізація, квазіоптимальна траєкторія управління

Поиск супремума оптимальной траектории управления практически недостижим в реальных условиях. Это связано с большим количеством степеней свободы управляемой системы, колебанием спроса, входных и выходных цен, существенной нелинейностью внутрисистемных процессов. Выходом в такой ситуации может быть разработка робастных методов квазиоптимального управления. Предлагаемый подход основан на установлении взаимосвязи управления преобразовательной системы с текущим уровнем производственных запасов

Ключевые слова: оптимизация связанных систем, квазиоптимальное управление, робастная оптимизация, квазиоптимальная траектория управления

1. Introduction

Modern scientific achievements have allowed reaching considerable heights in respect of new technologies of converting processes creation [1, 2], increasing in the extent of technological processes automation [3] and innovative products creation [4]. At the same time, the issues of optimal control processes formalization and automation are in the experimental developments stage [5, 6].

This state of the matter in the optimum control field is connected with the fact that the choice of the best case scenario is predetermined by a set of interconnected factors.

To achieve the greatest possible economic results, all enterprise systems have to function in coordination with the maximum financial efficiency.

The coordinated functioning of enterprise system objects, in turn, means the use of reasonable optimization criterion. However, depending on demand for this or that system production and system parameters, the optimization criterion structure changes.

For example, in the mode when demand exceeds supply, the converting class systems have to work in increased productivity mode. In cases when demand is lower than production capabilities, the time factor loses its importance.

Also, a formalization complexity of optimum control methods consists in that the control optimum trajectory formation is carried out in the mode of continuous changes in demand, weather conditions, price factors, etc.

At the same time, there is a need to change the productivity of converting processes depending on the production stock level. It is necessary, on the one hand, to minimize ballast stocks, and, on the other hand, as fast as possible to leave a zone of the increased deficiency risk.

All these factors lead to the fact that the optimum trajectory supremum search in actual practice, or in attempt of their modeling, is almost unrealizable. Therefore, there is the problem of formation of almost optimum (quasi-optimum) control trajectory which demands minimum measurements and search methods for the optimization task solution.

Thus, development of quasi-optimum-robust-control method as a function of demand and production stock level is an important scientific task.

2. Literature review and problem statement

For today, one of the weak points in the field of optimum control is the lack of a theoretical base for the optimal control trajectory search method formalization [7–9].

At the same time, the first item in the priority tasks list is the optimization criterion choice issue [10].

Now a large number of indicators have been developed and continue to be developed, which their creators offer for use as the operational processes optimization criteria [11].

In [13], 787 kinds of KPI balanced scorecards which developers offer for the operational processes efficiency problem solution have been allocated [12].

Having faced in practice with the imperfection of KPI, BSC, etc. balanced scorecards, the developers of optimization criteria try to find a way out in the creation of technical orientation indicators [14].

So, as the optimization criterion, it is proposed to use the minimum energy consumption [15], operation time [16], finding the shortest path in a graph [17] or technical and economic indicator [18].

In this case, the choice of the optimization criterion is only the first step towards the optimal control trajectory formation.

In view of the complexity of the control object model, in [19] the authors tend to believe that one of the most reliable methods for determining the optimal trajectory is mathematical modeling.

However, it is well known that this method is time consuming. Besides, in conditions of rapidly changing demand and pricing policy, the improvement of optimization quality in continuous search mode can be an unsolvable task.

Thus, in order to optimize the search process itself, it is required to develop a method, increasing the efficiency of determining the control path close to optimal.

3. The aim and objectives of the study

The aim of the work was finding the quasi-optimal control trajectory of the production system in the face of changing demand and stock level.

To achieve this aim, the following objectives were set:

– determination of the impact factors influencing the choice of control in converting class systems (CCS);

– selection of CCS optimization criteria depending on the level of demand in relation to productive opportunities;

– definition of interconnection between the stock rates and converting process productivity;

– determination of functional dependence between the output products stock level and converting process control.

4. Model of controlled systems interaction

Any production process of converting the certain input technological products into output consumer products can be fully optimized if the functions of forming the qualitative and quantitative parameters of the finished product are performed by separate systems [20].

A system that converts input technological products into output technological products with the set qualitative parameters is defined as a "class of converting system" (CCS).

The object that provides the CCS products buffering process to solve the problem of forming the output product with the given quantitative parameters is defined as a "dual system" (DS).

The controlled systems of such class, depending on the technological buffering process specifics, are determined by the concepts "storage system", "stock system" or "buffering system". The concept "dual system" is used because the distinctive feature of all systems of this class is the presence of two subsystems performing the control functions [21].

The structure uniting the CCS and DS is defined by the "production system" term (PS). Thus, the CCS provides production of the product with the set qualitative parameters, and the DS provides delivery of the output product with the required qualitative and quantitative parameters.

Those input technological products which arrive on the CCS input for target conversion are defined by the "products of directed action" concept (PDA).

That is, raw materials, product, work piece are the PDA.

Thus, the production system which provides the possibility of full optimization can be presented in the form of converting class online interacting systems and the dual system (Fig. 1).

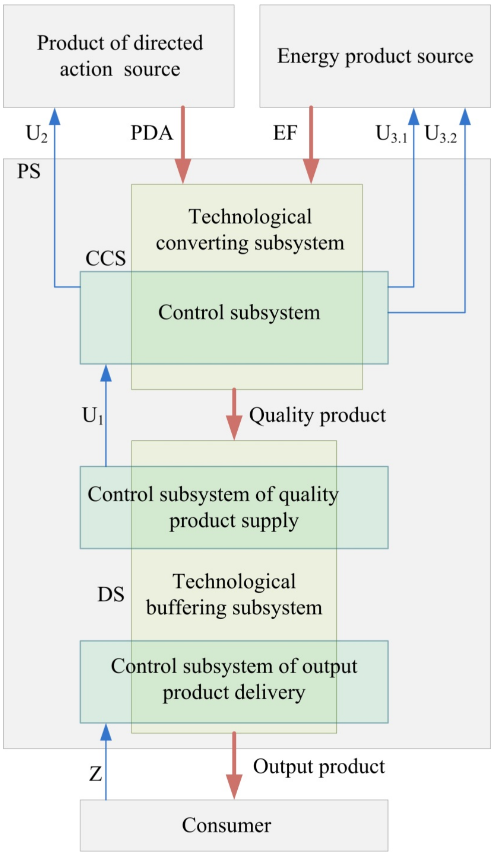

Fig. 1. The model displaying the principle of online interaction of production systems and systems – contractors: CCS – system of converting class; DS – dual system; PS – production system; PDA– product of directed action; EF – energy flow; $U_{3.1}$ – information control signal to supply the flow of energy product with the set intensity; $U_{3.2}$ – information control signal to interrupt the energy product supply; U_2 – information control signal to supply the product of directed action of the set volume; U_1 – information signal to convert and supply the qualitative product; Z – information signal to deliver the ready-made product

In the process of such interaction, the qualitative output products are generated on the dual system output. However, as the achievement of the output product given quality is formed within the set of admissible controls both of the class of converting system and the dual system, the time of optimum search increases substantially. There is a problem to optimize the search process itself.

5. Principle of executive system functioning

The process of converting the PDA into a finished product at the output of the production system is carried out as follows.

To get the finished product, the consumer or the consumption system gives the demand signal (Z) to the input of the dual system. If the current stock level of the dual system is higher than the lower dual system stock level (LL), the product is supplied to the consumer.

In this mode, the production system functions until the stock level reaches the lower level of the dual system buffering mechanism.

At the moment when the stock level of the dual system buffering system reaches the lower level, the supply control subsystem of the dual system generates a high-level pulse control information signal U_1 for the converting class system. This information product informs the converting class system about the need to replenish the stocks of the dual system.

That is, the dual system gives the U_1 task signal which reports to the system of converting class only that it needs a certain product. When to give the CCS product to the dual system input and to what extent, the dual system does not indicate.

The system of converting class, in turn, gives the U_2 information signal to the product of directed action source. This signal contains information about what the PDA volume is necessary to transfer to the CCS.

Having received the PDA, the system of converting class gives the information signal $U_{3.1}$ to the energy product source. At the same time, the signal $U_{3.1}$ bears information about what the energy product supply intensity should be.

As soon as the quality of the CCS product reaches the set level, the system of converting class gives the information signal $U_{3.2}$ to stop the supply of the energy product and transfers its output quality product to the dual system.

If, after the supply of the quality product to the dual system input has finished, the stock level does not reach the high level (HL), the supply control subsystem of the DS input product gives the high level of the task signal U_1 again.

After reaching the upper level, generation of high-level impulse signals U_1 stops and the system of converting class passes from the phase of active functioning into the passive phase of waiting.

Thus, for the system of converting class, there is the possibility to change both the PDA volume and the energy product supply intensity, while maintaining the output product set quality.

In turn, a dual system can set the lower and higher level of stock in the buffering mechanism.

6. The concept of finding of optimal control of the converter class system

Thus, the presence of two specialized systems in the production system architecture, each of which performs only one function, provides the possibility of an independent determination of the maximum number of controls.

In the system of converting class, the volume of the PDA and the energy product supply intensity can be set independently.

In the dual system, the lower and higher levels of stocks can be independently set.

The principle of determination of the dual systems stocks higher level is considered in [22]. The lower stock level is determined on the basis of the requirements for the dual system consumer demand continuous satisfaction, in conditions when the productivity of the converting class system and the demand itself change. In this case, the issue of determining the quasi-optimum control trajectory of the converting class system is solved if the problem of reasonable choice of the dual system lower stock level is resolved.

If to reduce the input and output products flows of the studied operation to comparable cost values, and then to add up them, we will receive the global model of the economic operation presented in the form of the deuce ($re(t)$, $pe(t)$) or ($re[n]$, $pe[n]$) for distributed-parameter operations [23].

In the case when the distributed nature of the products movement at the input and output of the CCS can be neglected (for example, the electricity does not need to be paid continuously in the process of energy consumption), then the global model ($re(t)$, $pe(t)$) or ($re[n]$, $pe[n]$) can be defined as a triple (RE, TO, PE) [3]. Here RE – a cost assessment of input operation products; TO – operation time; PE – a cost assessment of output operation products.

That is, each control of the CCS can be put in compliance, for example, with the triple of parameters of the simple economic operation global model (RE, TO, PE).

In order that the character of change in the three of parameters (RE, TO, PE) displayed the cybernetics of the process, it is necessary to consider all important factors which influence decision-making in the course of optimum control search.

So, the results of the production operation assessment are influenced by the value of energy consumption and equipment wear [24].

Most simply, the mechanism wear is determined in the tasks of portion liquid heating with the use of an electric heater. As the obvious accounting of energy consumption is possible in the heating system and there is a possibility of analytical wear determination [25], the research is conducted on the examples of the portion liquid heating.

The change of the RE, TO, PE parameters depending on control (U) (energy product supply intensity) for the operation of portion liquid heating is presented in Table 1 and in Fig. 2. The data of pilot studies are taken from [26].

These data can be used for the definition of optimum control or optimum control trajectory in the heating system of converting class.

We will consider how the choice of optimum control is carried out in the system of converting class when the level of demand exceeds productive opportunities.

In this case, the consumer queue is formed at the output of the production system, and the converting class system functions in the continuous mode.

In [23], it is found that during operation in the continuous mode, the optimization criterion is the resource efficiency indicator (efficiency indicator).

Generally, for an efficiency assessment, we can use $t \in [0,\ t_a]$ the ELF indicator (1) [27] which has passed verification for consistency with the efficiency concept [28]

$$ELF = \frac{\int_{t_a}^{t_d}\left(\int_{t_a}^{t}\left[\int_{t_0}^{t} pe(t)dt - \int_{t_0}^{t}\left|re(t)\right|dt\right]dt\right)dt}{\int_{t_0}^{t_a}\left[\int_{t_0}^{t}\left(\int_{t_0}^{t}\left|re(t)\right|dt\right)dt - \int_{t_0}^{t}\left(\int_{t_0}^{t} pe(t)dt\right)dt\right]dt}, \qquad (1)$$

where t_a is the moment of the actual end of the operation time which is defined at the moment of functional expressions equality

$$\int_{t_0}^{t}\left(\int_{t_0}^{t} pe(t)dt\right)dt = \int_{t_0}^{t}\left(\int_{t_0}^{t}\left|re(t)\right|dt\right)dt, \quad t_d = t_a + 1$$

is the end time of the operation potential effect determination [6].

Table 1

The change in the portion liquid heating basic operation parameters depending on control

U	*TO*	*RE*	*PE*
0.02	8	0.017	0.018
0.04	4.8	0.0146	0.018
0.06	3.06	0.01344	0.01800
0.08	2.22	0.012852	0.01800
0.1	1.75	0.012432	0.01800
0.12	1.43	0.01225	0.01800
0.14	1.21	0.012012	0.01799
0.16	1.05	0.011858	0.01797
0.18	0.925	0.01176	0.01793
0.2	0.83	0.011655	0.01787
0.22	0.75	0.01162	0.01775
0.24	0.685	0.01155	0.01756
0.26	0.63	0.011508	0.01726
0.28	0.58	0.011466	0.01682
0.3	0.54	0.011368	0.01620
0.32	0.5	0.01134	0.01530
0.34	0.47	0.0112	0.01397
0.36	0.46	0.011186	0.01223

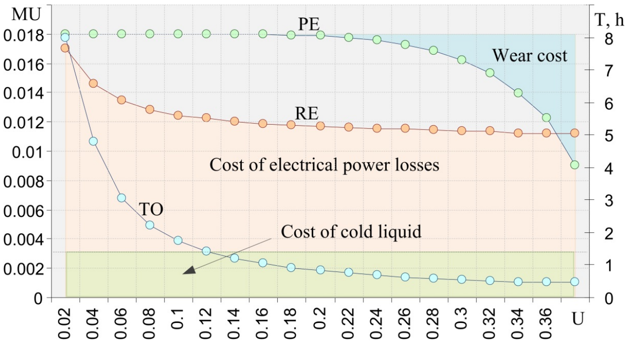

Fig. 2. Dependence of change of liquid portion heating system basic parameters on control: MU — monetary unit

For an assessment of the operations presented in the form of the three (*RE*, *TO*, *PE*), the expression of *ELS* (2) as a special case of general expression has been obtained (1)

$$ELS = \frac{\left(PE - RE\right)^2 T_p^2}{RE \cdot PE \cdot T_{op}^2}, \qquad (2)$$

where $T_p = t_d - t_a = 1$.

If to define the operations efficiency (Table 1), we get the following dependence of the CCS operations efficiency on control (Fig. 3).

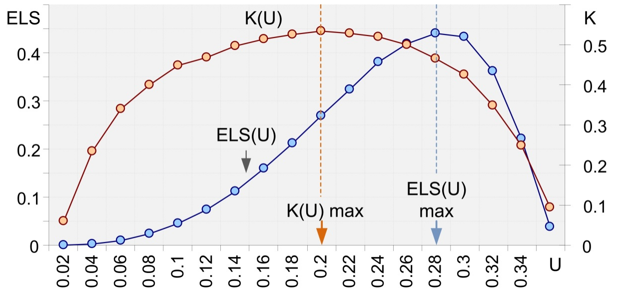

Fig. 3. Change of efficiency and value added coefficient depending on control

This dependence shows that in the mode when demand exceeds supply, the CCS optimum control corresponds to the energy product supply with an intensity of U=0.28. This control is designated by U_R.

The following characteristic mode of operation of the production system (PS) corresponds to the situation when the demand for the PS products is lower than the level of productive capacity of the CCS.

In this case, when the reserves of the DS buffering mechanism reach the higher level, the control of the DS temporarily stops the active phase of the CCS. The following start of the CCS occurs when stocks decrease to the lower level.

After that, the buffering mechanism of DS accumulates the CCS products but, with an increase in the stock level, it doesn't immediately transfer the output products to the consumer.

Such a functioning mode is conceptually similar to the situation where the CCS product at the end of operation *A* cannot immediately be transferred to another operation. In this case, the waiting operation *B* appears in the operational process (Fig. 4).

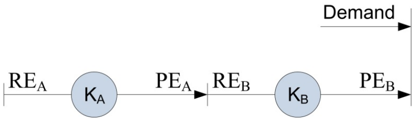

Fig. 4. The model of *A* operation and related *B* waiting operation

A distinctive feature of *B* operation is that it has a zero value-added coefficient K_B, because PE_B=RE_B, K_B=(PE_B−−RE_B)/RE_B=0.

That is, in this case, the operational process consists of two operations: *A* converting operation and *B* waiting operation. In addition, it is necessary to investigate for effectiveness not the operation *A* but the replacement operation *C* (Fig. 5).

In replacement operations, RE_C=RE_A, TO_C=TO_A+TO_B and PE_C=PE_A.

Let us consider the operations (Table 1) assuming that the CCS can not immediately transfer its output product to the consumer and the replacement operation time is the same

(Table 2, Fig. 3). For definiteness, the replacement operation time is decided to be one.

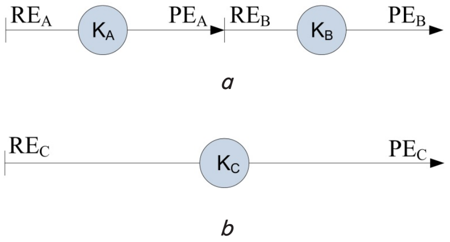

Fig. 5. Models of equivalent operational processes: *a* – operational process consisting of *A* and *B* operations; *b* – replacement operations *C*

Table 2

The change in the basic parameters of the portion liquid heating operation depending on control with fixed operation time and the calculated values of *ELS* and *K* criteria

U	*TO*	*RE*	*PE*	*K*	*ELS*
0.02	1	0.017	0.018	0.059	0.0033
0.04	1	0.0146	0.018	0.233	0.0440
0.06	1	0.01344	0.01800	0.339	0.0860
0.08	1	0.012852	0.01800	0.401	0.1146
0.1	1	0.012432	0.01800	0.448	0.1385
0.12	1	0.01225	0.01800	0.469	0.1498
0.14	1	0.012012	0.01799	0.498	0.1653
0.16	1	0.011858	0.01797	0.515	0.1753
0.18	1	0.01176	0.01793	0.525	0.1807
0.2	1	0.011655	0.01787	0.533	0.1853
0.22	1	0.01162	0.01775	0.528	0.1822
0.24	1	0.01155	0.01756	0.521	0.1782
0.26	1	0.011508	0.01726	0.500	0.1667
0.28	1	0.011466	0.01682	0.467	0.1485
0.3	1	0.011368	0.01620	0.425	0.1266
0.32	1	0.01134	0.01530	0.349	0.0902
0.34	1	0.0112	0.01397	0.247	0.0490
0.36	1	0.011186	0.01223	0.093	0.0079

In that case, the maximum efficiency of *AB* process corresponds to control U=0.2. The control, in which the maximum of value added is achieved, is denoted by U_L.

The maximum of the *AB* process efficiency can be achieved in another way. For this, it is enough to define which operation of type *A* has a maximum value-added coefficient *K=PE/RE* (Table 2, Fig. 3).

Thus, in conditions when the time factor isn't important, the choice of the best operation of CCS is made by the *ESL* criterion for *TO*=const or by the value-added coefficient criterion.

In the reviewed example, the choice of the best CCS operation was carried out in the assumption that operations of DS are delay operations which don't create the value added.

Actually, the buffering operation can be considered as a delay operation only in that case when the stock level is rather high. Besides, the buffering processes perform several important functions. At the DS output, the consumer with a high degree of probability can receive a product without delay, with the required quantitative parameters and low expenses of the CCS starting processes.

The choice of the higher level of stocks in DS is connected with the consequences of the CCS first start-up losses and binding of stocks of the output product. The higher the level of stocks, the lower losses of the first start but the greater the amount of the output products ballast stocks.

Therefore, with an increase in the higher level of reserves, the efficiency of the PS first increases, and then reaches the maximum and begins to decline.

The higher level of stocks is defined by the maximum efficiency of the PS processes [22].

Thus, the higher level of DS stocks is connected with minimization of consequences of the CCS first start-up losses.

For example, the energy product of the first heating operation is necessary not only for liquid heating, but also for tank heating.

The start of stopped extrusion equipment, for the manufacture of plastic products, requires the pre-cleaning from the plastic which has stiffened at the output.

Operations of stocks replenishment, which are carried out in the cycle, need additional starting losses only for the first operation of the cycle.

The higher the higher level of DS reserves, the more replenishment operations in the cycle are performed by the CCS without starting losses.

In this case, the reduced costs of the replenishment process decrease and the efficiency of the PS processes grows. However, the level of DS reserves also grows.

At a certain level of reserves, their influence begins to affect the PS efficiency more than the first start-up expenses decrease.

Since a lower level of *HL* corresponds to the equal number of replenishment operations with a decrease in productivity, the efficiency of the PS operation, under steady-state demand, increases.

Thus, in a situation where the productive capacity of the CCS exceeds the average level of demand, and the level of the DS reserves is close to the higher level (the DS performs the delay function), the optimization of the CCS operational processes should be carried out by the criterion of maximum value-added ratio.

In this case, the CCS reduced productivity mode leads to negative consequences when the level of reserves reaches the lower level of stocks.

At this point, the DS forms a signal for the CCS to replenish stocks.

However, in the time interval, as long as the CCS performs the first longest operation of the replenishment cycle, the reserves level of DS continues to decline.

Thus, the lower the CCS productivity, the higher should be the lower level of DS reserves. In addition, it is necessary to take into account the probabilistic nature of demand. For a decrease in the probability of the finished goods deficiency, it is desirable to quickly escape from the lower stock level.

In such a situation when requirements to the CCS functioning mode are predetermined by the features of DS processes, the use of the optimization criterion of CCS operational processes, in an explicit form, becomes impossible.

It is possible to achieve the maximum efficiency of the executive system processes in case the CCS control trajectory is defined by control processes of DS.

In this case, U_L control of CCS, which gives the maximum value added, and U_R control of CCS, at which the maximum efficiency is reached, are restrictions on the optimum control trajectory of CCS processes.

If to connect the numerical U_R value with the HL value, and the numerical U_L value with the LL value, then the linear expression which connects the control (U) of CCS with restrictions [U_R, U_L] and the current level of the buffering mechanism (h) of DS will have the form

$$U=\frac{U_R(HL-LL)+(U_L-U_R)(h-LL)}{HL-LL}. \tag{3}$$

We will consider how the choice of the CCS control is practically carried out:

1. The control of CCS is determined, at which the maximum value of K (U_L control) and the maximum value of ELS (U_R control) is reached. For example, U_L=0.2 and U_R=0.28.

2. The value of the higher (HL) and lower (LL) stock levels of DS is defined. For example, LL=4, and HL=12.

3. The current stock level (h) of DS is defined and the control U for CCS is calculated.

So, if the current stock level is h=4, then we get the following

$$U=\frac{0.28(12-4)+(0.2-0.28)(4-4)}{12-4}=0.28.$$

That is, the CCS control with the maximum productivity corresponds to the lower stock level of DS.

If the current stock level is h=12, then we get

$$U=\frac{0.28(12-4)+(0.2-0.28)(12-4)}{12-4}=0.2.$$

That is, the control of CCS with the minimum productivity corresponds to the higher stocks level of DS.

And at last, if the stock level of DS is intermediate, for example, h=8, we get $U=0.24$.

Thus, the control trajectory of the CCS can change according to the law that is close to optimal, depending on the change in the DS reserves level.

7. The experimental research and the results

For experimental verification of the production system functioning efficiency increasing possibility with the use of the proposed method, the EFFLI software designer was taken [29].

The interface model in the form of EFFLI objects is shown in Fig. 6.

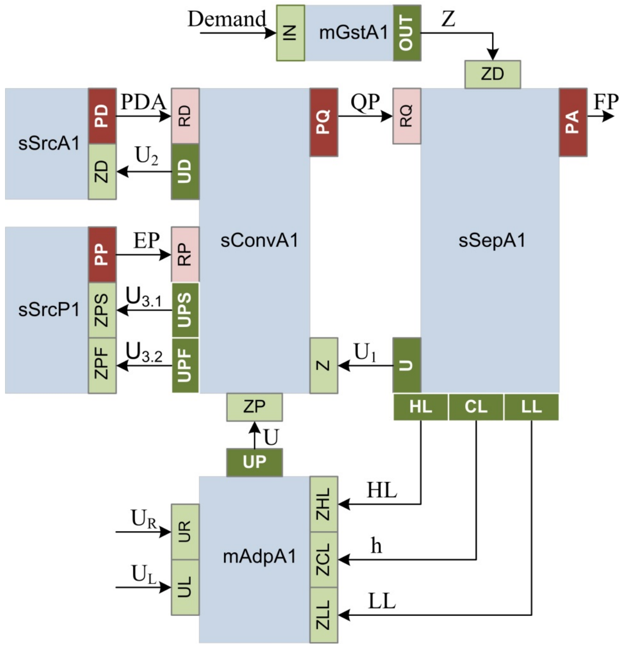

Fig. 6. The interface model for researching the method of forming the optimal control trajectory of the heating system, depending on the demand level and the current dual system stocks level

Here, *mGstA1* – the mechanism of stationary demand modeling; *IN* – the section for setting the level of demand; *OUT* – the section for issuing a demand signal; *SSrcA1* – the model of the PDA feed source; *PD* – the section for issuing the PDA; *ZD* – the section for the receiving of the task for the PDA delivery; *SSrcP1* – the model of the source of the energy product delivery; *PP* – the energy product delivery section; *ZPS* – the section of receiving the task for delivery of the energy product of the set intensity; *ZPF* – the section of receiving the task for interruption of the energy product supply; *sConvA1* – the model of the liquid heating system; *Z* – the section of receiving the task signal for the heated liquid portion supply; *ZP* – the section of receiving the task signal for the value of intensity of the energy product giving; *UPS* – the control signal output section for supplying the energy product of a certain intensity; *UPF* – the section for issuing a reference signal to stop the energy product supply; *UD* – the section of giving the control signal on supply of a certain amount of PDA; *RD* – the section of the PDA giving; *RP* – the energy product supply section; *PQ* – the quality product delivery section; *sSepA1* – the dual system model for the heated liquid buffering; *ZD* – the signal for the output product delivery; *LL* – the section for setting the lower stocks level; *HL* – the higher stock level setting section; *CL* – the section for issuing the current value of the DS reserves level; *U* – the control delivery section for replenishment of DS reserves; *RQ* – the section for the quality product supply; *PA* – the section of the output product delivery; *mAdpA* – the mechanism of the control formation of the energy product supply; *ZLL* – the section for giving the signal for the lower stock level; *ZHL* – the section for giving the signal for the higher stock level; *ZCL* – the section for giving the signal of the current stock level; *UL* – the section of giving the control, at which the maximum CCS value added is reached; *UR* – the section of giving the control, at which the maximum CCS efficiency maximum is reached; *UP* – the section of giving the CCS optimum control.

Realization of the formation function of the quasi-optimum control trajectory, according to expression (3), is provided by the *mAdpA1* mechanism.

The working model is available in the reference [30].

Implementation of the software designer was carried out in the Excel environment using the built-in programming language Visual Basic for Applications.

Preliminary preparation of the Excel environment itself for the possibility of starting the simulation process is reduced to setting up Excel parameters that enable to run the macros.

At the first stage of the study, the control of the U_L, at which the maximum value added was reached and control of the U_R, at which the maximum efficiency of the CCS was achieved, were determined.

It was found that U_L=0.35, and U_R=0.75.

The lower stock level of DS has been established at the mark *LL*=2, and the higher stocks level – at the mark *HL*=10.

It is possible to change the established borders of the lower and high stocks levels on the *sSepA1* tab in D4 and D5cells to the right of designations of *LL* and *HL* sections.

The diagram (Fig. 7) shows how the stock level of DS changes when giving the control corresponding to the maximum CCS efficiency *U*=75. At the same time, the production system efficiency is *ELF*=0.019.

In order for the control system of the converter class to remain unchanged, on the mAdpA1 mechanism tab, it is necessary to set the values 75 in the cells D3 and D4 to the right of the *UL* and *UR* sections.

The demand level (0.0015 units) is set in cell D3, to the right of the section name *IN*.

The model is started from the “Display” tab by pressing the “Start” button. In the upper left corner, the system time countdown begins. At the end of 50 units of system time, the model functioning automatically ends.

The modeling results can be viewed on the *mAdpA_R* tab.

It can be seen that the stock level quickly increases. If we assume that the peak demand can reach 20 units, we can single out a deficit risk zone.

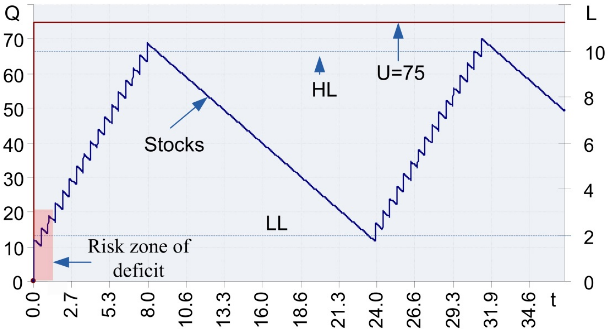

Fig. 7. Change of the stock level in the production system at stable demand and system of converting class control level

Having set the mode of energy product giving at the level of *U*=35 units, we get the schedule of change of stocks in conditions when the maximum CCS value added is reached.

For this purpose, on the *mAdpA1* tab mechanism, it is necessary to establish the value 35 in D3 and D4 cells to the right of designations of *UL* and *UR* sections.

It can be seen that the exit from the deficiency risk zone increases approximately by 10 times (Fig. 8).

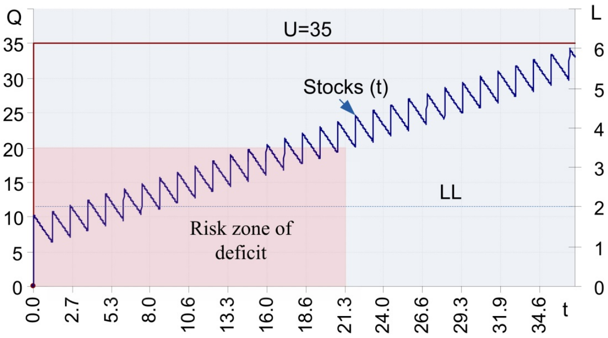

Fig. 8. Change of the stock level in the production system at stable demand and system of converting class control level

Fig. 9 shows the diagrams of the *U* control and DS stocks change in conditions when the control of the energy product supply in CCS is a function of the DS stock level, calculated according to (2). The efficiency of the production system, in relation to the control of CCS with the constant control level (*ELF*=0.019) at the same time increases and becomes equal to *ELF*=0.026.

To set this mode, on the *mAdpA1* mechanism tab, you need to set the value 35 in cell D3, the value 75 in cell D4, to the right of the *UL* and *UR* sections.

The level of demand (0.0015 units) is established in D3 cell, to the right of the name of *IN* section.

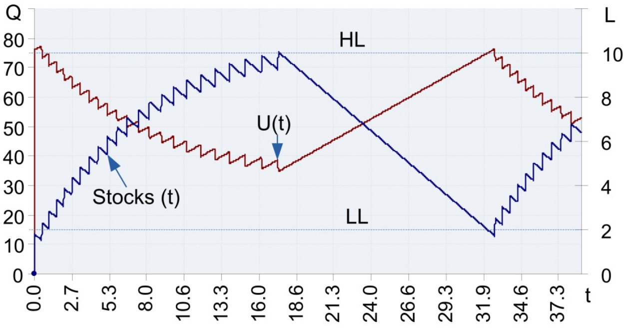

Fig. 9. Change of the stock level in the production system at stable demand and control of the converting class system which changes ~~in~~ as a function of the stock level of the dual system

Fig. 10 shows how the system functions in the conditions of the balance of demand and productive opportunities of CCS. In such functioning mode, the DS doesn’t interrupt the CCS work.

For setting this mode, on mAdpA1 mechanism tab it is necessary to establish the value 35 in D3 cell, the value 75 in D4 cell to the right of designations of *UL* and *UR* sections.

The level of demand (0.002 units) is established in D3 cell to the right of the *IN* section name.

It is obvious that such operating mode of the production system is preferable as the expenses of start-up of CCS are absent. However, the efficiency of such operational process has to be higher as well for the objective reasons. Reserves do not reach the higher level because the average level of demand rises.

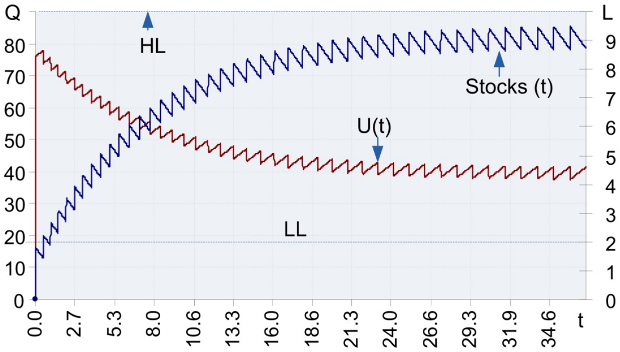

Fig. 10. Change of the stock level in the production system at stable demand and level of control of the converting class system which changes ~~in~~ as a function of the dual system stock level

8. Discussion of the results of the research related to definition of the optimal control trajectory of the production system as a function of demand and stock level

As the results of the study showed, the system of converting class and the dual system, buffering the CCS products, are related systems. And the choice of optimal control is not, in general, the optimization of the operational processes of each of these systems separately. Therefore, the search for optimal control must be defined as the search for the optimal trajectory of the control change of the production system.

Since the optimal control depends on the mode of CCS operation, the demand and cost parameters of technological products, the search for the optimal control trajectory is a difficult task.

The shape of the ideal optimal control trajectory will, of course, differ from the shape of the trajectory, which can be obtained as a result of the implementation of the control dependence of CCS on the level of the DS reserves. However, the search for such an ideal trajectory, in the process of the search regime, is likely to be an ineffective measure.

To solve this problem analytically is hardly possible, since the model of the production system is extremely complicated even in relatively simple cases.

The complexity of the optimal control trajectory search method is related to the sensor errors, the probabilistic nature of demand and the inevitable change in the cost estimates of input products for a number of reasons.

In real production conditions, there may not be time to search for a better trajectory, since under the conditions of the instability of the influencing factors, the process will last indefinitely.

9. Conclusions

1. The impact factors influencing on the principles of the CCS control choice have been determined. Among them: the level of demand for finished products; the amount of losses of the first start; the size of permissible control range; the values of the lower and higher levels of the dual system stocks.

2. It is found that, depending on the demand level, the optimal control trajectory for the CCS should be changed. This means that the structure of the optimization criterion changes with the external factors. It is also found that under the conditions where the time factor is not significant, the choice of control using the efficiency index is equivalent to the choice using the value added coefficient.

3. It has been found that if the level of the dual system resources is low, the exit from the zone of maximum deficit risk must be implemented in the mode of increased productivity.

4. The expression is obtained that connects the control of the converting class system to the dual system stocks level. At the same time, the permissible control~~s~~ domain extreme values of the converting class system correspond to the minimum and maximum dual system stock~~s~~ levels. Using the resulting expression provides the ability to exclude the search mode for selecting the optimal control trajectory for the converting class system.

The definition of functional dependence allows us to realize the principle of quasi-optimal robust control of the production system.

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