Ministry of Education and Science of Ukraine
Black Sea Universities Network

ODESA NATIONAL UNIVERSITY OF TECHNOLOGY

International Competition of Student Scientific Works

BLACK SEA SCIENCE 2022

PROCEEDINGS

ODESA, ONUT 2022

Ministry of Education and Science of Ukraine

Black Sea Universities Network

Odesa National University of Technology

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Proceedings

Odesa, ONUT 2022

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Proceedings of International Competition of Student Scientific Works «Black Sea Science 2022» contain the works of winners of the competition.

The author of the work is responsible for the accuracy of the information.

Odesa National University of Technology, 2022.

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INTRODUCTION

International Competition of Student Scientific Works “Black Sea Science” has been held annually since 2018 at the initiative of Odesa National University of Technology (formerly Odesa National Academy of Food Technologies) with the support of the Ministry of Education and Science of Ukraine. It has been supported by Black Sea Universities Network (the Association of 110 higher education institutions from 12 countries of the Black Sea Region) since 2019, and by Iseki-FOOD Association (European Integrating Food Science and Engineering Knowledge into the Food Chain Association) since 2020.

The goal of the competition is to expand international relations and attract students to research activities. It is held in the following fields:

- Food science and technologies
- Economics and administration
- Information technologies, automation and robotics
- Power engineering and energy efficiency
- Ecology and environmental protection

The jury includes both Ukrainian and foreign scientists. In the 4 years that the competition has been held, the jury included scientists from universities of 24 countries: Angola, Azerbaijan, Benin, Bulgaria, China, Czech Republic, France, Georgia, Germany, Greece, Israel, Italy, Kazakhstan, Latvia, Lithuania, Moldova, Pakistan, Poland, Romania, Serbia, Slovakia, Switzerland, Turkey, USA.

At the same time, every year the geography has expanded and the number of foreign jury members has increased: from 46 jury members representing 25 universities from 12 countries in 2018, to 73 jury members of the 46 universities from 19 countries in 2022.

More than a thousand student research papers have been submitted to the competition from both Ukrainian and foreign institutions from 25 countries: China, Poland, Mexico, USA, France, Greece, Germany, Canada, Costa Rica, Brazil, India, Pakistan, Israel, Macedonia, Lithuania, Latvia, Slovakia, Romania, Kyrgyzstan, Kazakhstan, Bulgaria, Moldova, Georgia, Turkey, Serbia.

The interest of foreign students in the competition grew every year. In 2018, the students representing 15 institutions from 7 countries have submitted 33 works. In 2021 the number of submitted works increased to 73, authored by the students of 40 institutions from 18 countries.

The competition is held in two stages. In the first stage, student research papers are reviewed by members of the jury who are experts in the relevant fields. In the second stage of the competition, the winners of the first stage have the opportunity to present their work to a wide audience in person or online.

All participants of the competition and their scientific supervisors are awarded appropriate certificates, and the scientific works of the winners are included in the electronic proceedings of the competition. Every year the competition receives a large number of positive responses from Ukrainian and foreign colleagues with the desire to participate in the coming years.

3. INFORMATION TECHNOLOGIES, AUTOMATION AND ROBOTICS

CONTROL SYSTEM OF CONDENSING DRYING PROCESS WITH ENERGY RECOVERY USING HEAT PUMP

Author: Denis Chaplygin
Advisor: Dmytro Kovalchuk
Odessa National Academy of Food Technologies (Ukraine)

Abstract. *The purpose of the work is to develop a system of automatic control of the drying process, which would support adjustable variables in the regulatory zones in both steady and transient modes of operation.*

Research methods and tools - in identifying the properties of the object of control used methods of imaginary active and passive experiment with further processing of their results; control object models and control systems were developed in Simulink / Matlab environment; parametric synthesis of the control system is carried out by the method of optimizing the quality of its operation; the development of the advanced system was carried out analytically using the apparatus of transfer functions.

The obtained results - the received system of the increased dynamic accuracy which supports adjustable variables in regulatory zones both in steady, and in transient operating modes

Scope - the system can be used to modernize the process of production of dried fruits.

Significance of work and conclusions - the developed system has advantages in comparison with traditional ACS which are used in practice.

Key words: *heat pump, drying unit, heater, mathematical model, simulation model, channel model, perturbation model.*

I. INTRODUCTION

In the last decade, heat pump technologies are increasingly used not only in the field of heat supply to heat consumers, but also in heat technology processes, one of which is the drying of various materials and, in particular, food raw materials. For example, fresh fruits contain about 75-90% water and 5-15% sugar, so they spoil easily, wither quickly, rot. If you reduce the moisture content in fresh fruit to 10-20%, they become resistant to microorganisms, do not spoil, in appropriate conditions can be stored for a long time quite suitable for consumption for a long time. But due to the high heat capacity of water, drying processes are very energy-intensive, so the use of energy-efficient modes of drying processes is an urgent task.

The introduction of the condensing drying process with energy recovery through the use of a heat pump can provide a significant increase in its energy efficiency. However, existing heat pump drying control systems are usually not able to maintain energy-efficient modes, the required dynamic accuracy of reproduction of the set temperature and moisture content of the drying agent, which reduces energy efficiency and may reduce the quality of finished products.

One of the most effective and proven ways to achieve this goal is to increase the intellectual level of key process control algorithms (TP).

One of such processes is the process of condensation drying of raw materials with energy recovery through the use of a heat pump. This process is crucial in shaping the quality of finished products, so increasing the requirements for the quality of regulation of mode parameters is quite natural.

The paper presents studies of the process of condensation drying of raw materials with energy recovery through the use of a heat pump as a control object (OK), which resulted in mathematical models (MM) of the main control channels and perturbations. Based on the obtained models, process control algorithms have been developed that provide high quality control of regulated variables. Simulation modeling of the behavior of the control system, which implements the developed control algorithms, is performed, and its operability is confirmed.

II. ANALYTICAL REVIEW OF LITERATURE

There are various methods of automatic control of the drying process, which differ in technological schemes, the number of adjustable parameters and control methods.

There is a method of automatic control of the grain drying process in a mine grain dryer, including measuring and regulating the grain temperature and drying agent temperature in each zone of drying, measuring and regulating grain moisture at the exit of the grain dryer and compensating for delays in this control channel [Патент України № 35801. Спосіб автоматичного управління процесом сушіння зерна в шахтній зерносушарці F26B 25/22 / Степанов М.Т., Ловчев О.М.; Заявл. 02.04.2008. Опубл. 10.10.2008. Бюл. № 19]

The disadvantage of this method of automatic control is the low quality of the finished product due to the harmful mutual influence of the control circuits, which is quite significant.

III. OBJECT, SUBJECT AND METHODS OF RESEARCH

3.1. Selection of the object for modernization of the automation system, description and analysis of the technological process and the corresponding equipment implemented by him.

The essence of the technological process of condensation drying of raw materials with energy recovery through the use of a heat pump is to remove moisture from the raw material and convert it into a dry product. The technological process is implemented in the drying chamber. The technological scheme of the process is given in Fig.1.

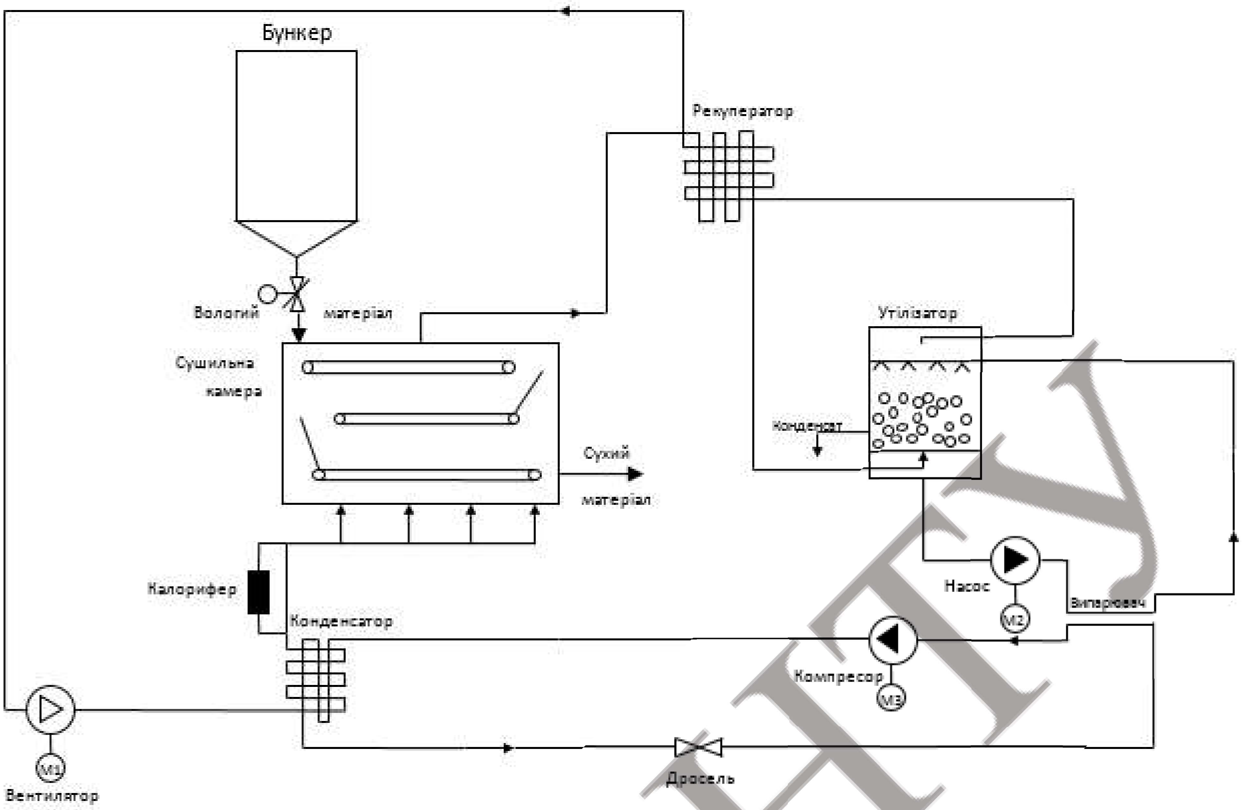


Fig.1.– Technological scheme of the drying process

In the stationary mode of operation of the installation, the flow of drying agent with a temperature of 60 ^{0}C is fed into the drying chamber. After passing the material, the stream enters the recycler, where excess heat is disposed of. After passing the recycler, the flow of drying agent passes through the recuperator. After passing through the recuperator, the flow of drying agent enters the condenser of the heat pump, while heating, and, heating up in the heater, enters the drying chamber. The cycle repeats.

The drying unit, which was developed in the laboratory of the Department of ATP and RS ONAFT is a drying chamber with a heat pump.

The nominal consumption of the installation is 40 kg / h. The equipment also includes a heat pump, the electric drive of the compressor of which has a capacity of 5 kW.

The purpose of the drying process is to obtain a product with specified quality indicators. In industrial production, the achievement of the goal can be justified only when the technological process makes sense to implement, when a number of requirements for the technological process are met.

It is expedient to realize technological process of drying if:

- there is a sufficient supply of raw materials for work, ie, if the stock is not less than 1 ton;

- there must be electricity in the power supply circuits of the heat pump compressor with average network parameters;

- There should be a place to ship the finished product.

The technological process of drying is a thermal process associated with the transfer of heat from the drying agent to the wet material through their interaction in the drying chamber. An important condition for the normal functioning of the technological process is the filling of the drying chamber with the product. We will parameterize the technological scheme. The results of parameterization are shown in Fig.2.

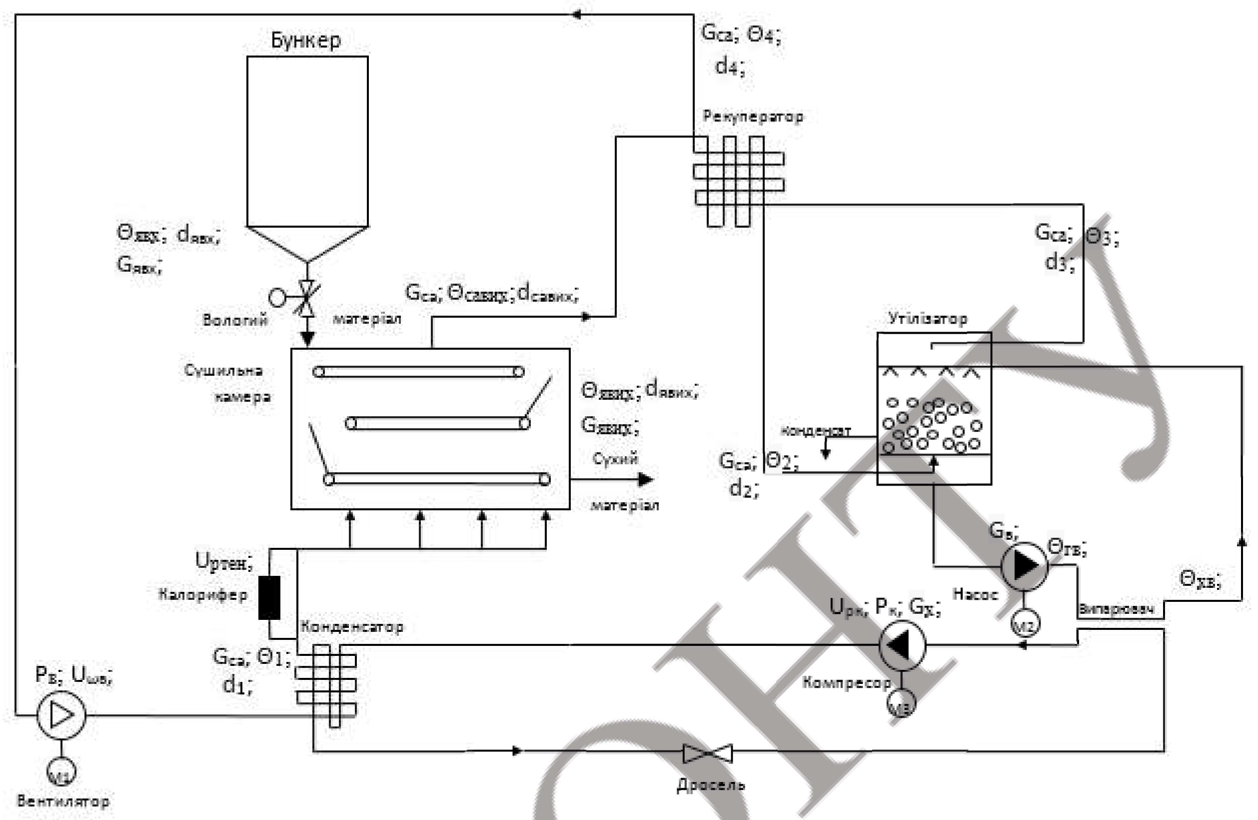


Fig. 2. – Parameterized technological scheme of the drying process

Designation on the parameterized technological scheme:

$G_{са}$ – consumption of drying agent, м^3/с ;

$\Theta_{савх}$ – the temperature of the drying agent at the entrance to the drying chamber, set by the drying technology, ^oC ;

$d_{савх}$ – moisture content of the drying agent at the entrance to the drying chamber, g/кg ;

$\Theta_{савих}$ – the temperature of the driving agent at the outlet of the driving chamber, ^oC ;

$d_{савих}$ – the moisture content of the drying agent at the outlet of the drying chamber, g/кg;

Θ_0 – the temperature of the drying agent at the inlet of the condenser, ^oC ;

d_0 – the moisture content of the drying agent at the inlet of the condenser, g/кg;

Θ_1 – the temperature of the drying agent at the outlet of the condenser, ^oC ;

d_1 – the moisture content of the drying agent at the outlet of the condenser, g/кg;

Θ_2 – the temperature of the drying agent at the inlet to the recycler, ^oC ;

d_2 – the moisture content of the drying agent at the inlet to the recycler, g/кg;

Θ_3 – the temperature of the drying agent at the outlet of the recycler, ^oC ;

d_3 – the moisture content of the drying agent at the outlet of the recycler, g/кg;

Θ_4 – the temperature of the drying agent at the outlet of the heat exchanger, ^oC ;

d_4 – moisture content of the drying agent at the outlet of the heat exchanger, g/кg;

$G_в$ – water consumption, м^3/с;

$\Theta_{хв}$ – cold water temperature, ^oC ;

$\Theta_{гв}$ – hot water temperature, ^oC ;

$G_{\text{х}}$ – refrigerant consumption, $м^3/с$;
$G_{\text{явх}}$ – consumption of wet material, $м^3/с$;
$\Theta_{\text{явх}}$ – temperature of wet material, ^{o}C ;
$d_{\text{явх}}$ – moisture content of wet material, g/кg;
$G_{\text{явих}}$ – consumption of dry material, $м^3/с$;
$\Theta_{\text{явих}}$ – temperature of dry material, ^{o}C ;
$d_{\text{явих}}$ – moisture content of dry material, g/кg;
$P_{\text{к}}$ – heat pump compressor power, кWт;
$P_{\text{в}}$ – fan power, кWт;
$U_{\text{рк}}$ – heat pump compressor speed, % х.р.о
$U_{\text{ртен}}$ – power of the electric heater, % х.р.о
$U_{\text{ωв}}$ – fan speed, % х.р.о

Table 1. – Table of regulations

Name of parameters	Marking	Unit of measurement	Nominal value of the parameter	Permissible deviations from face value		
				Long $(t \to \infty)$	Short-term $(0<t<<\infty)$	
				size	size	time, sec
1	2	3	4	5	6	7
The temperature of the drying agent at the inlet of the drying chamber	$\Theta_{\text{савх}}$	^{0}C	60	±1	±5	200
Moisture content of the drying agent at the outlet of the drying chamber	$d_{\text{савих}}$	g/kg	45	±1	±5	200
The temperature of the water entering the recycler	$\Theta_{\text{хв}}$	^{0}C	24	±0,5	±3	100с

3.2. Development of a conceptual model of the object of regulation

For the drying process, the control actions include the power of the heater, which changes the temperature of the drying agent at the inlet to the drying chamber ($U_{ртен}$), the speed of the heat pump compressor ($U_{рк}$) and the fan speed that controls the flow rate of the drying agent ($U_{ωв}$). For the drying process, it is expedient to include the temperature of the recirculating drying agent $\Theta_{рса}$ in the controlled disturbances. All other input actions are classified as uncontrolled disturbances. The deterministic component of these perturbations is additively applied to the control actions, and the stochastic component is applied to the adjustable coordinate.

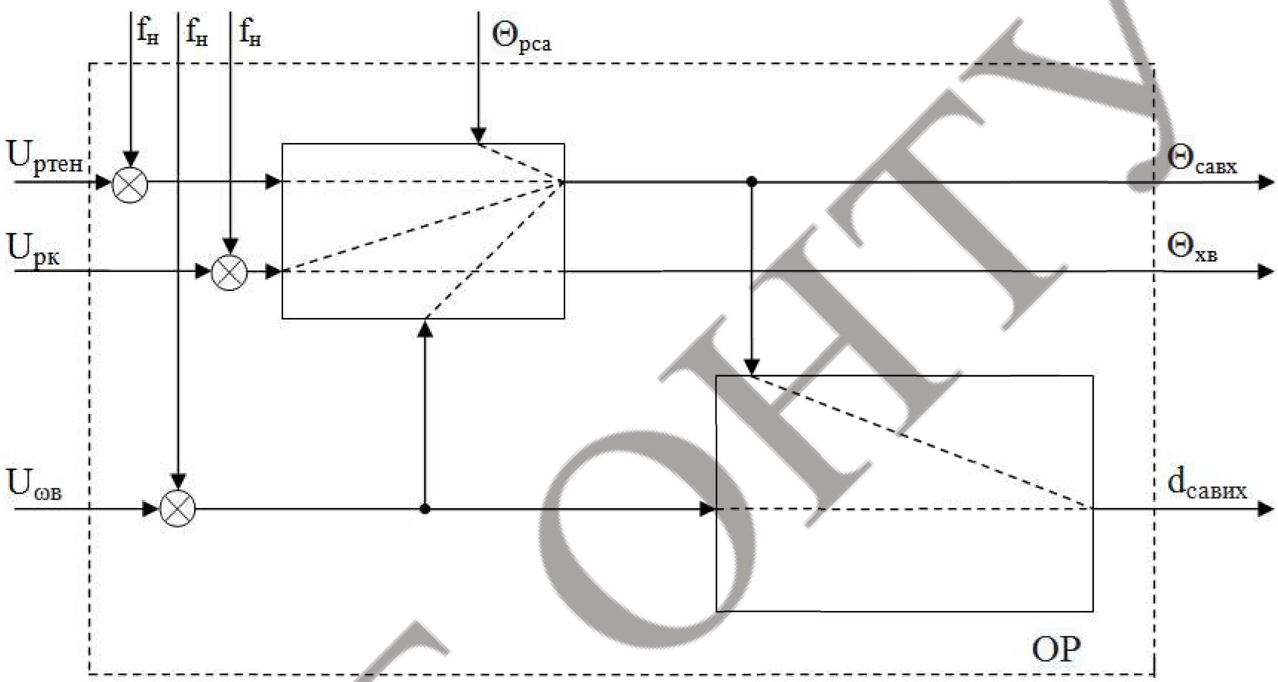


Fig. 3.– Block diagram of the drying process as an object of regulation

3.3 Identification of models of channels of transformation of object of regulation

Before starting the experiments, it is advisable on the basis of a priori data, based on the physical nature of the object, to pre-evaluate the properties of the channels whose models are to be identified.

For the technological process of drying both on the control channel and on the channel of controlled perturbation OK has the property of self-alignment, because the technological process is thermal. Increasing the control action (power of the electric heater) will increase the drying temperature.

To identify the models of OK channels, we plan and conduct an active experiment.

Active experiment plan

1. By changing the control action, we achieve the value of the adjustable coordinate, which would be in the vicinity of its nominal value. For our OK value $U_{ртен}$ = 60% x.p.o. , $U_{рк}$ = 60% x.p.o. and $U_{ωв}$ = 60% x.p.o. will correspond to the values of the adjustable coordinates $\Theta_{савх} = 60^0C$, $\Theta_{хв} = 24^0C$,

$d_{савих}$ = 45 g/kg.

2. We are waiting for the end of the transition process in the channels and the onset of a stable mode in which the original variables will stop changing.

3. Let's change control actions step by step on 10% x.p.o., noting the moment of the beginning of their change.

4. Register the change of output variables before the onset of new stable modes, the input action in this case may not be registered.

The results of the active experiment are shown in Fig. 4 – 6

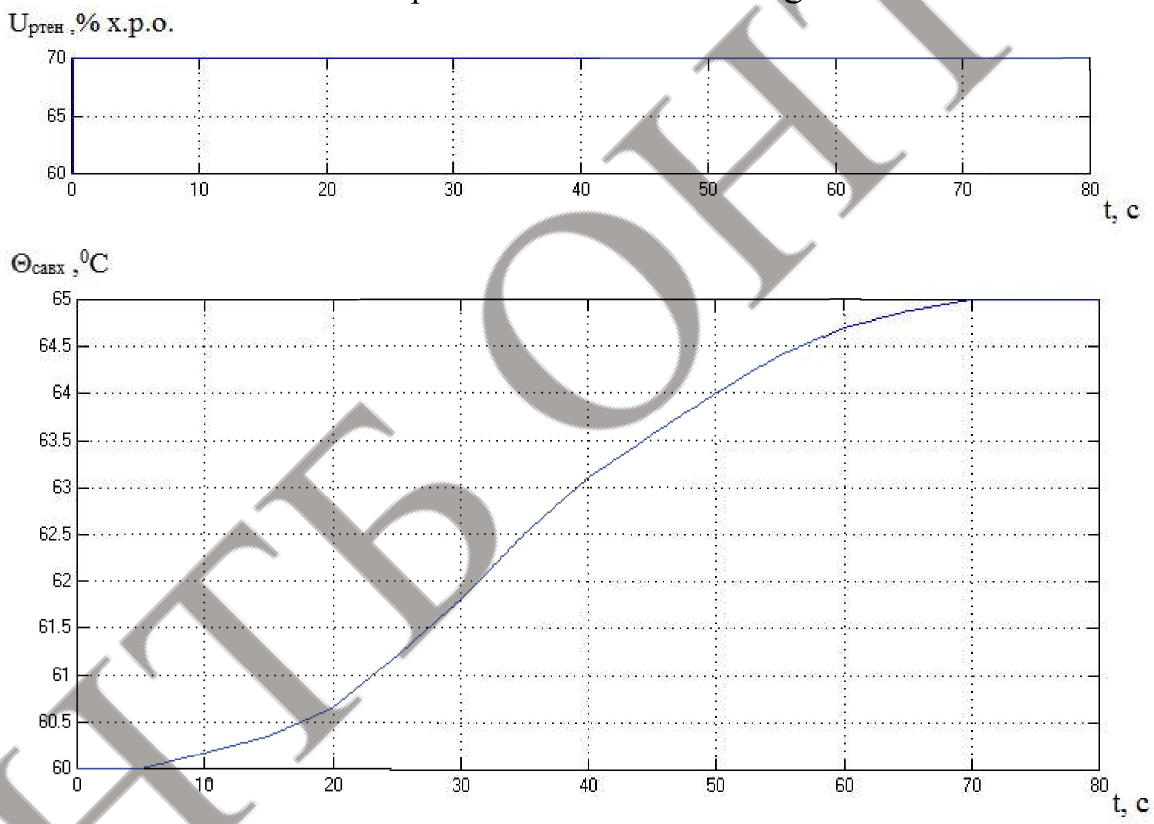


Fig. 4. – The results of an active experiment on the channel «$U_{ртен}$ - $\Theta_{савх}$»

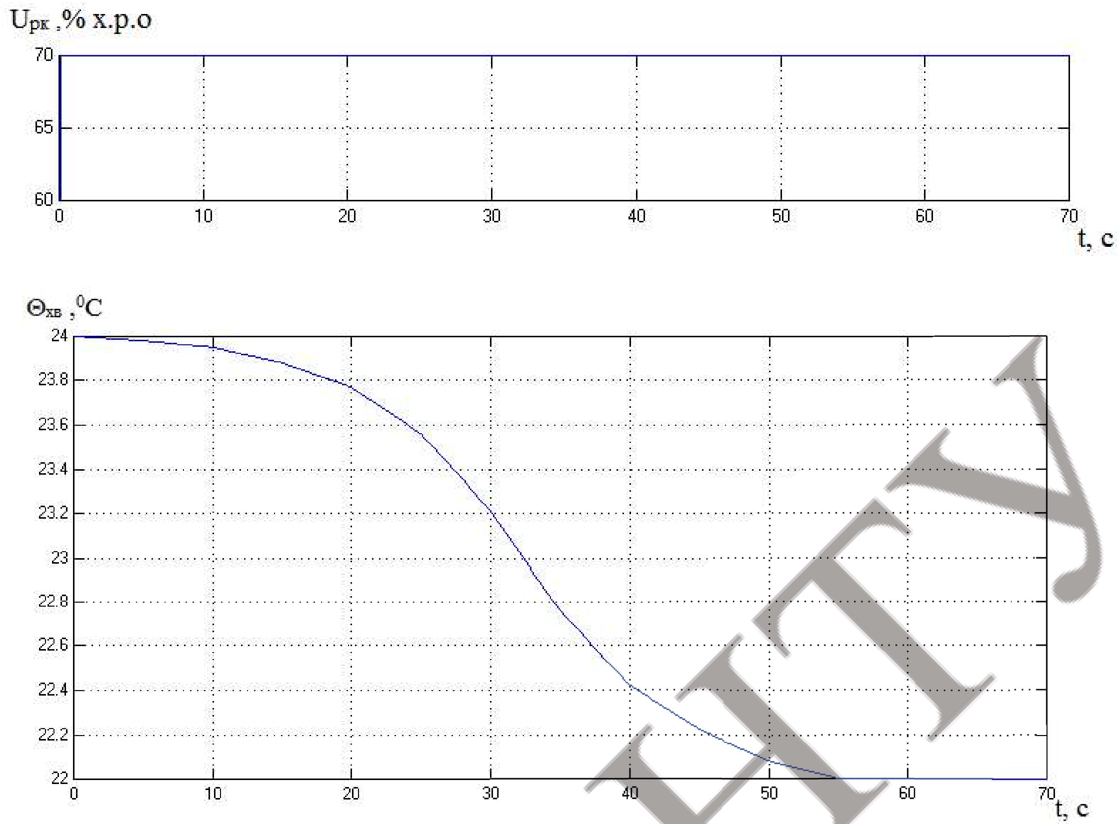


Fig. 5. – The results of an active experiment on the channel «$U_{рк}$ - $\Theta_{хв}$»

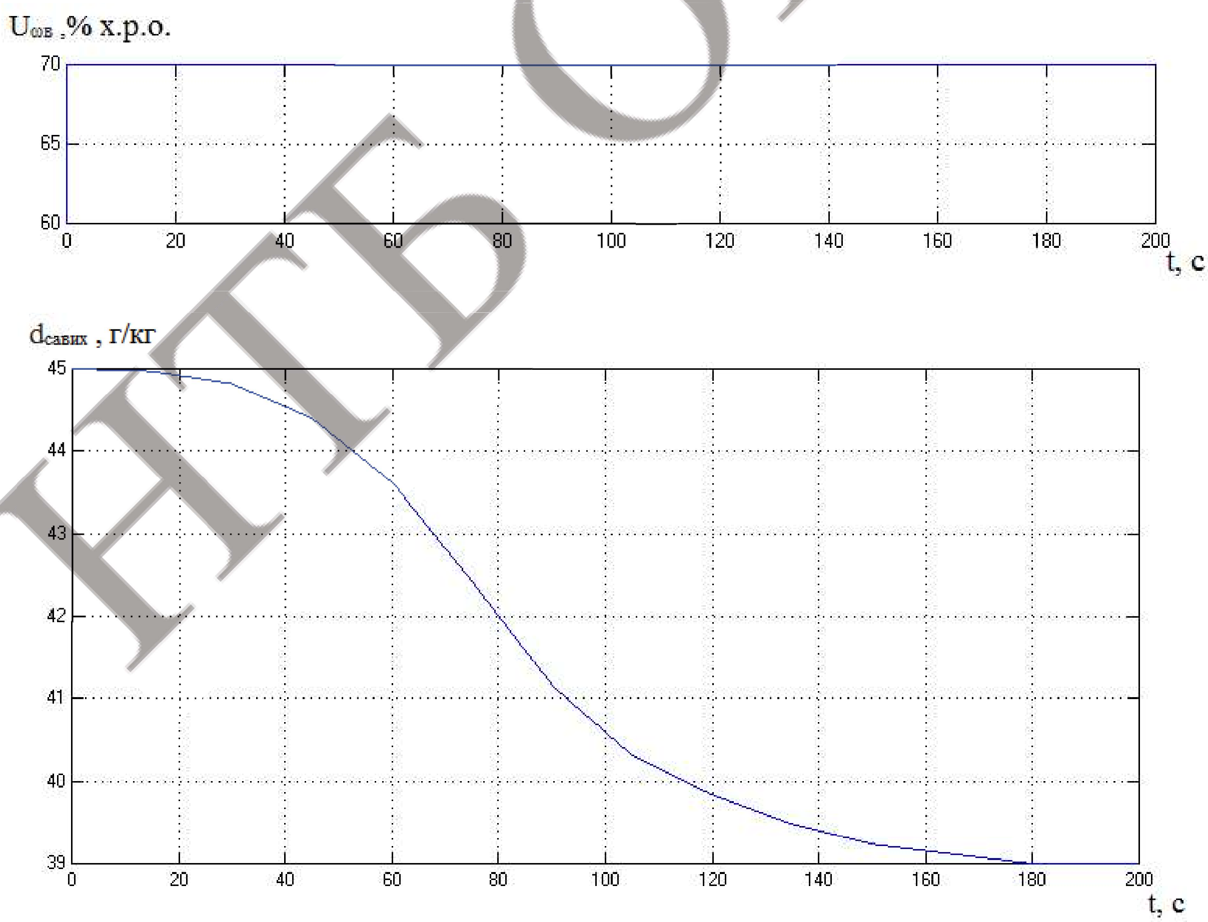


Fig. 6 – The results of an active experiment on the channel «$U_{ωв}$ - $d_{савих}$»

The following are the transfer functions for the 1st and 2nd order models for all OK channels.

Transfer function of the 1st order channel model «$U_{ртен} - \Theta_{савх}$» looks like:

$$W_0(p) = \frac{0{,}5 \cdot e^{-20{,}9p}}{19{,}6p+1} \quad (1)$$

Transfer function of the 2nd order channel model «$U_{ртен} - \Theta_{савх}$» looks like:

$$W_0(p) = \frac{0{,}5 \cdot e^{-11{,}85p}}{(13{,}6p+1)^2} \quad (2)$$

Transfer function of the 1st order channel model «$U_{рк} - \Theta_{хв}$ » looks like:

$$W_0(p) = \frac{-0{,}2 \cdot e^{-23{,}54p}}{11{,}5p+1} \quad (3)$$

Transfer function of the 2nd order channel model «$U_{рк} - \Theta_{хв}$ » looks like:

$$W_0(p) = \frac{-0{,}2 \cdot e^{-16{,}68p}}{(8{,}61p+1)^2} \quad (4)$$

Transfer function of the 1st order channel model «$U\omega в - d_{савих}$» looks like:

$$W_0(p) = \frac{-0{,}6 \cdot e^{-53{,}04p}}{36{,}16p+1} \quad (5)$$

Transfer function of the 2nd order channel model «$U\omega в - d_{савих}$» looks like:

$$W_0(p) = \frac{-0{,}6 \cdot e^{-34{,}86p}}{(25{,}65p+1)^2} \quad (6)$$

Static properties of OK are described by static characteristics (models) of channels. They reflect the relationship between the input and output coordinates (variables) of the OK channels in statically constant modes, ie after the attenuation of all transient components of these variables.

To identify models of static characteristics of the OK, we will conduct an active experiment. The results of the experiment to determine the static characteristics of the channels are summarized in tables 2-4 and in Fig. 7 - 9.

Table 2

The results of the experiment to determine the static characteristics of the OK channel «$U_{ртен} - \Theta_{савх}$ »

$U_{ртен}$, % х.р.о	$U_{рк}$, % х.р.о	$U_{\omega в}$, % х.р.о	$\Theta_{савх}$, °C
60	60	60	60
70	60	60	65
80	60	60	70
50	60	60	55
40	60	60	50
0	60	60	30

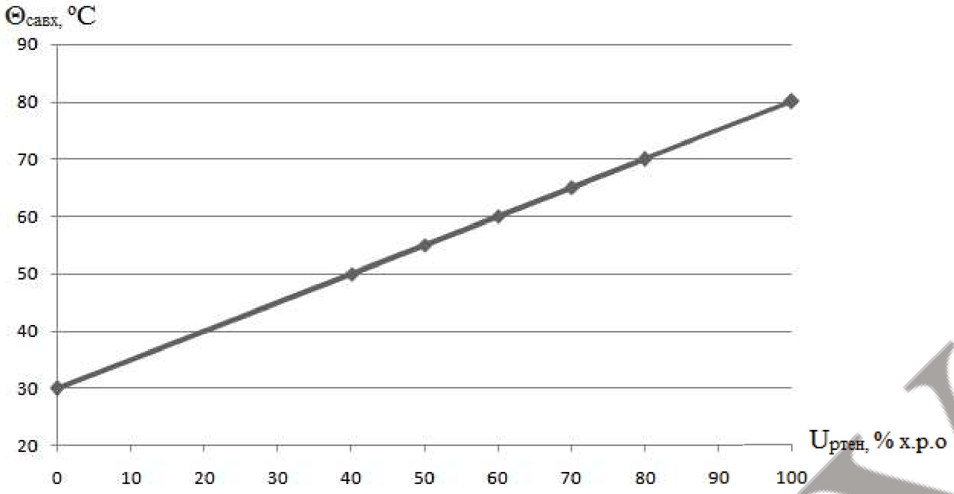


Fig. 7 – The results of the experiment to determine the static OK channel characteristics «$U_{ртен}$ – $\Theta_{савх}$ »

Table 3

The results of the experiment to determine the static characteristics of the OK channel «$U_{рк}$ – $\Theta_{хв}$ »

$U_{ртен}$, % х.р.о	$U_{рк}$, % х.р.о	$U_{ωв}$, % х.р.о	$\Theta_{хв}$, °C
60	60	60	24
60	70	60	22
60	80	60	20
60	50	60	26
60	40	60	28
60	0	60	40

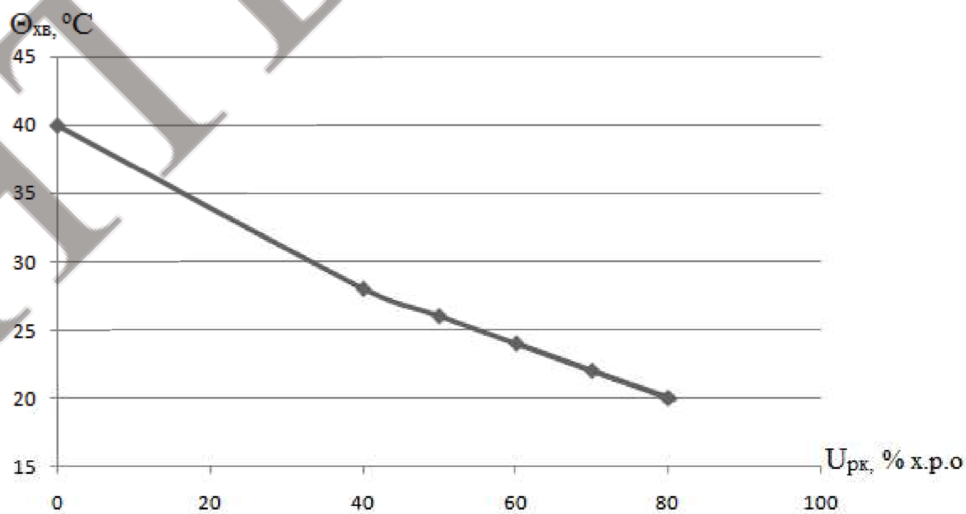


Fig. 8 – The results of the experiment to determine the static OK channel characteristics «$U_{рк}$ – $\Theta_{хв}$ »

Table 4
The results of the experiment to determine the static characteristics of the OK channel «$U_{ωв}$ – $d_{савих}$ »

$U_{ртен}$, % х.р.о	$U_{рк}$, % х.р.о	$U_{ωв}$, % х.р.о	$d_{савих}$, g/kg
60	60	60	45
60	60	70	39
60	60	80	34
60	60	50	50
60	60	40	57

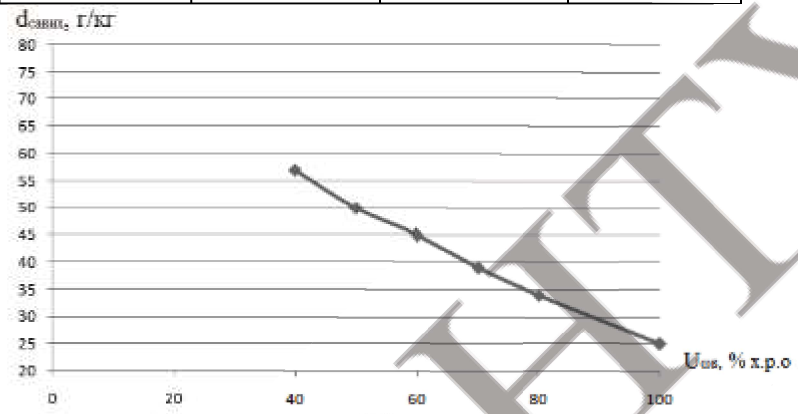


Fig. 9 – The results of the experiment to determine the static OK channel characteristics «$U_{ωв}$ – $d_{савих}$ »

3.4 Identification of deterministic and random models components of uncontrolled disturbances

Models of uncontrolled perturbations should be represented as the sum of four components. Moreover, the deterministic component ($f_{НД}$) it is expedient to lead to a controlling action, and quasi-deterministic and stochastic components ($f_{НС}$) it is advisable to bring to an adjustable coordinate (look. Fig. 10).

The model of controlled perturbation by analogy with the model of uncontrolled perturbations can be represented by four components that will be applied to the input of the channel of controlled perturbations.

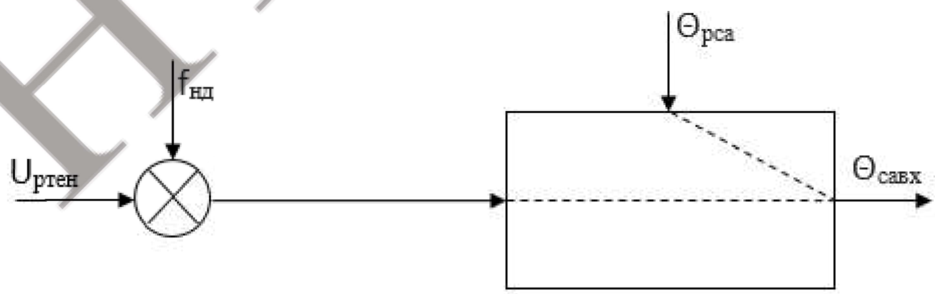


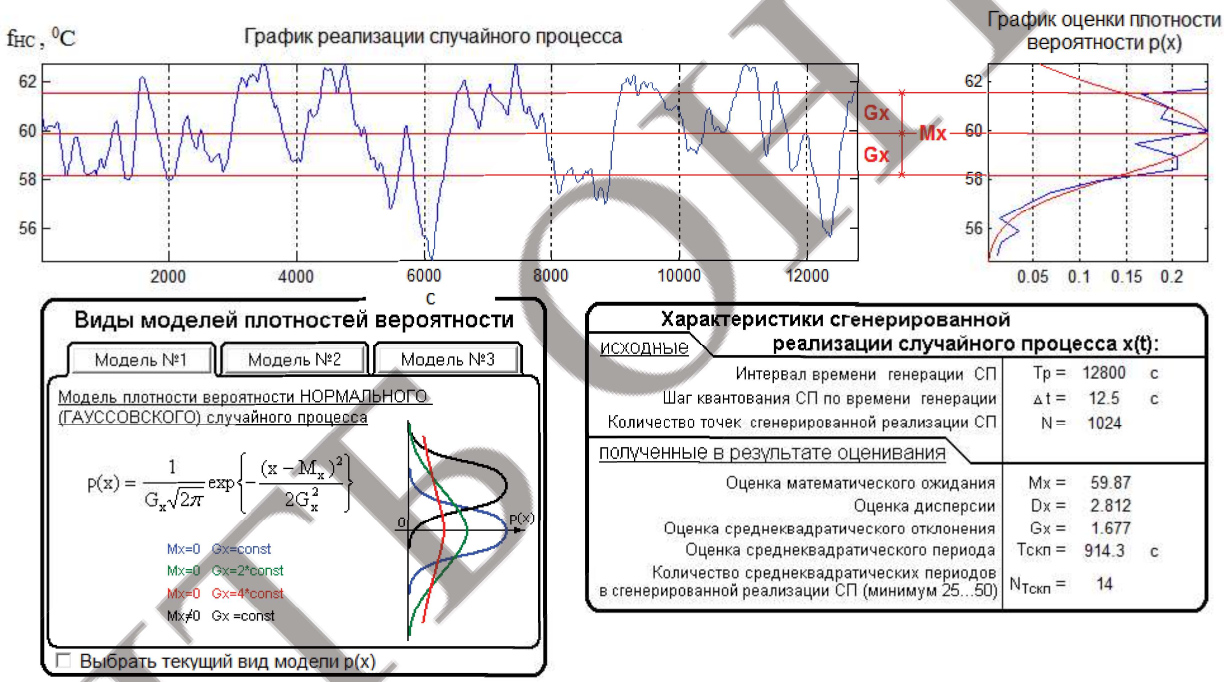
Fig. 10 – Block diagram of adding coordinate perturbations

Since it is not possible to obtain real experimental data, you can use a data generator for educational purposes.

Fig. 11 – The results of generating a random process corresponding to the signal of uncontrolled perturbation for the studied OK

You can use the IdSoft environment program to identify models of controlled and uncontrolled coordinate perturbations.

The results of estimating the probabilistic characteristics of a random process corresponding to uncontrolled perturbations are given in Fig. 12, a corresponding to controlled perturbation – in Fig. 13.



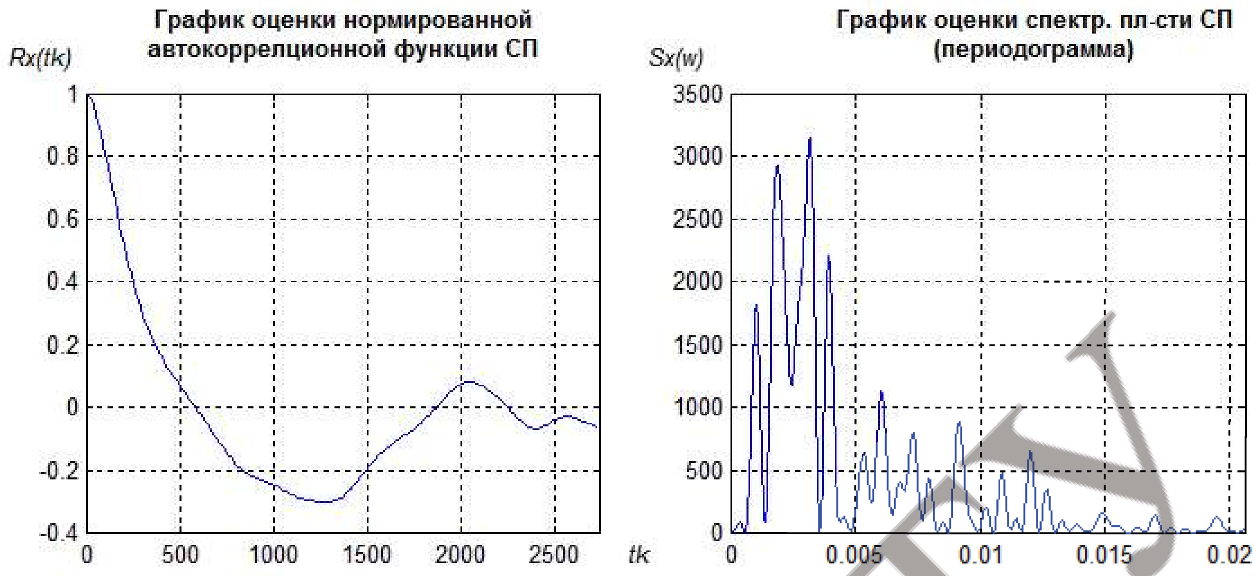


Fig. 12 – The results of estimating the probabilistic characteristics of a random process corresponding to uncontrolled perturbations

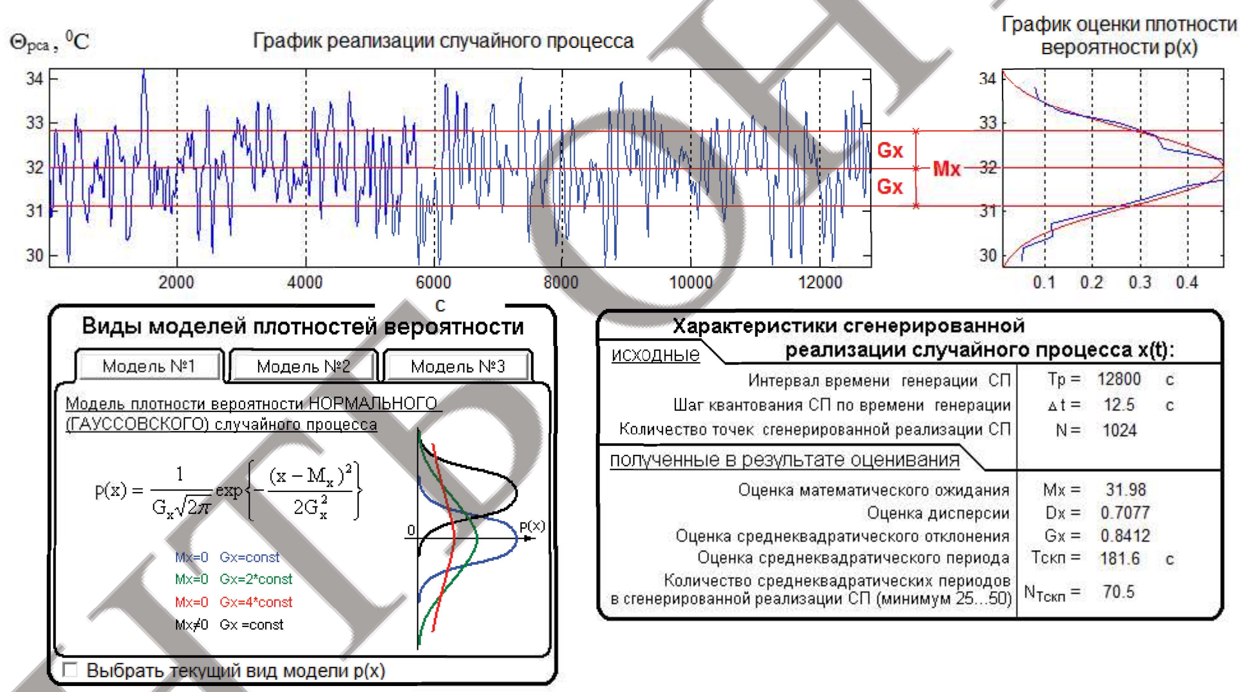


Fig. 13(1)– The results of estimating the probabilistic characteristics of a random process corresponding to controlled perturbations

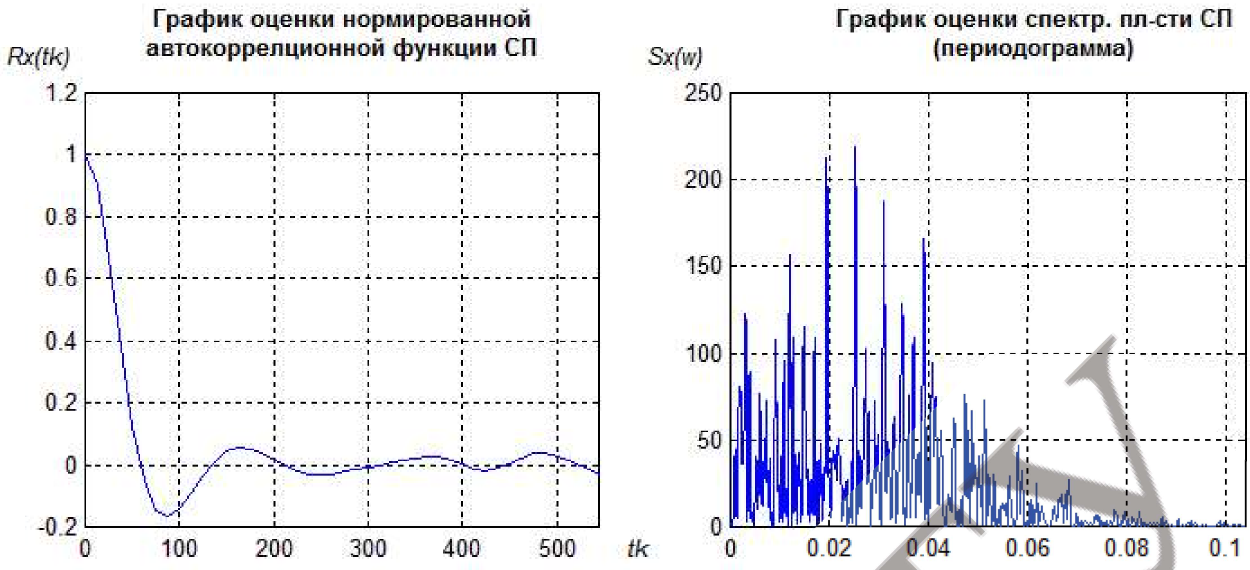


Fig. 13– The results of estimating the probabilistic characteristics of a random process corresponding to controlled perturbations

As can be seen from the simulation results, the OK model fairly accurately reflects the experimental data. This means that the resulting OK model is adequate.

To reproduce the model of perturbations as stochastic processes with given properties, we will use the method of forming a filter. It can be represented as such a structural scheme of modeling (Fig. 14).

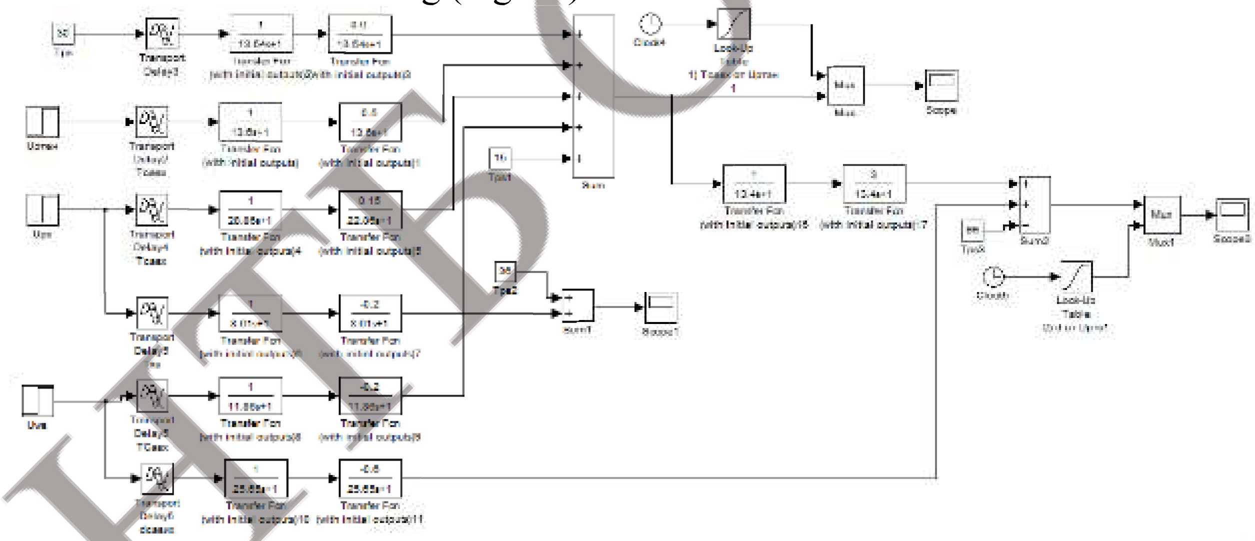


Fig. 14 – Model modeling scheme OK

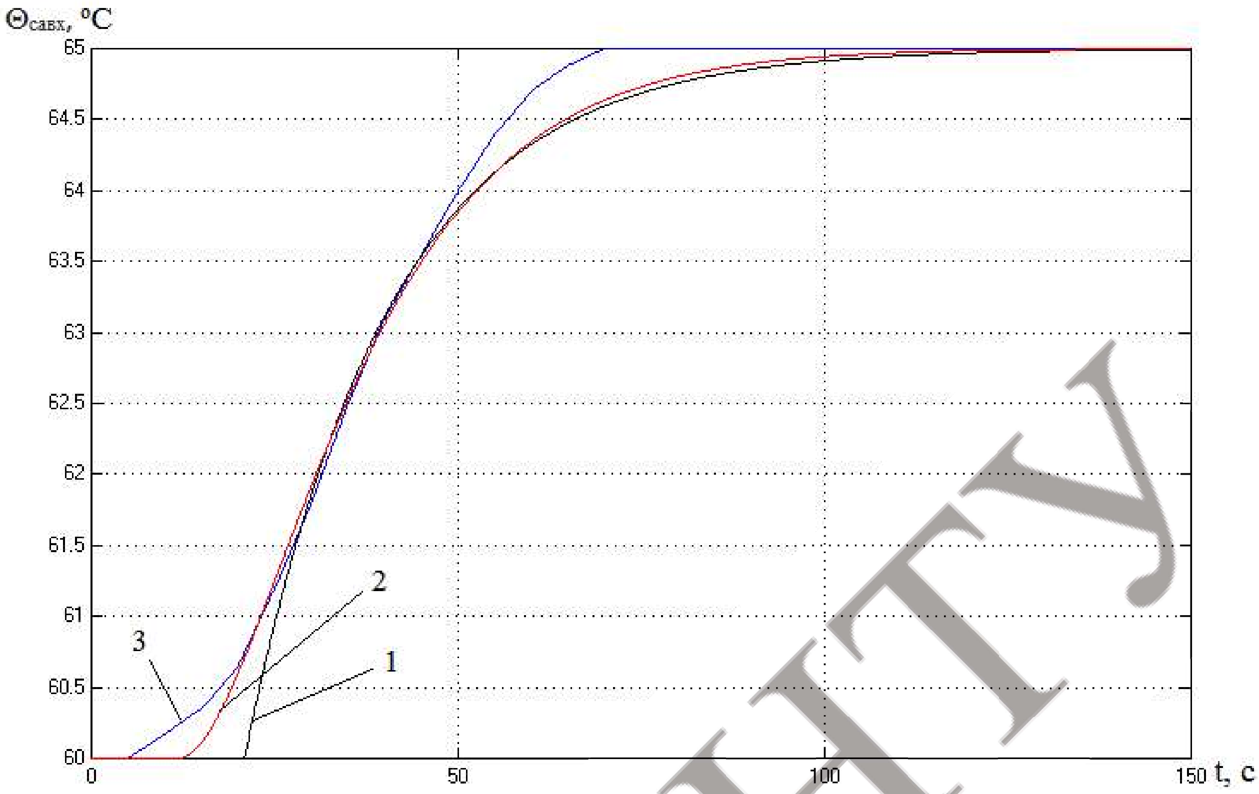


Fig. 15 – The result of channel simulation «$U_{ртен}$ – $\Theta_{савх}$», where 1 is a model of the 1st order; 2- 2nd order model; 3- experimental data.

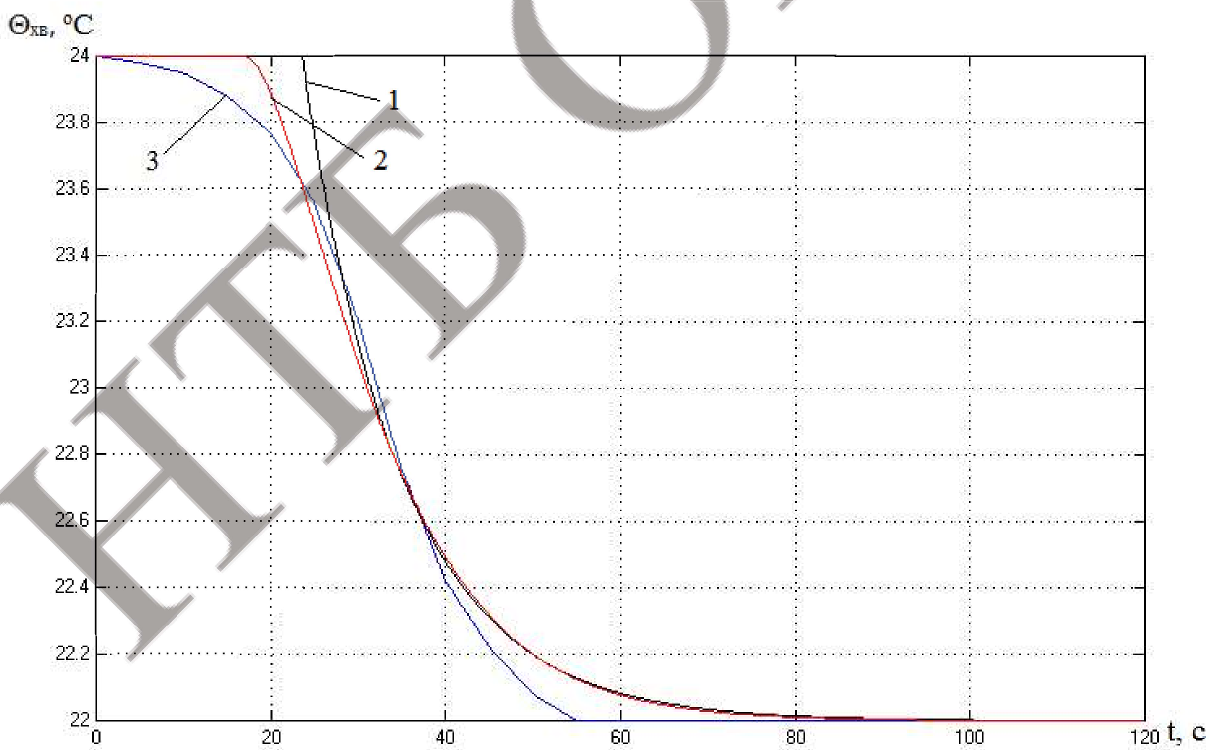


Fig. 16 – The result of channel simulation «$U_{рк}$ – $\Theta_{хв}$», where 1 is a model of the 1st order; 2- 2nd order model; 3- experimental data.

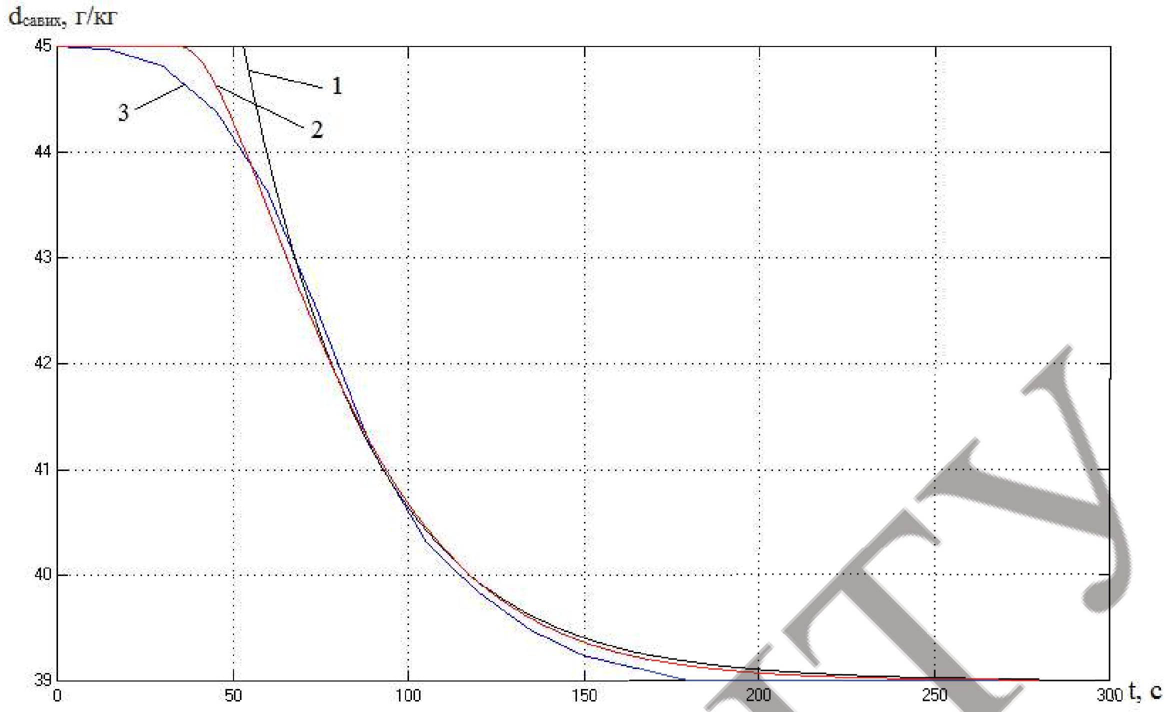


Fig. 17 – The result of channel simulation «$U_{фв}$ – $d_{савих}$», where 1 is a model of the 1st order; 2- 2nd order model; 3- experimental data.

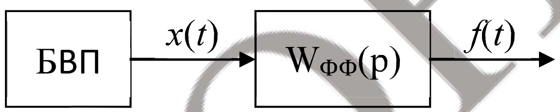


Fig. 18 – Block diagram of the model of stochastic processes

Forming filter parameters: : $k = 3{,}5$; $T = 187$ c; $\xi = 0{,}6$. The scheme of modeling the final forming filter is shown in Fig. 19, and the simulation results - in Fig. 20.

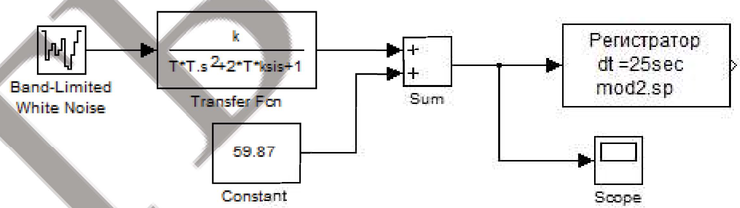


Fig. 19 – Uncontrolled perturbation simulation scheme with generating filter having adjusted parameters

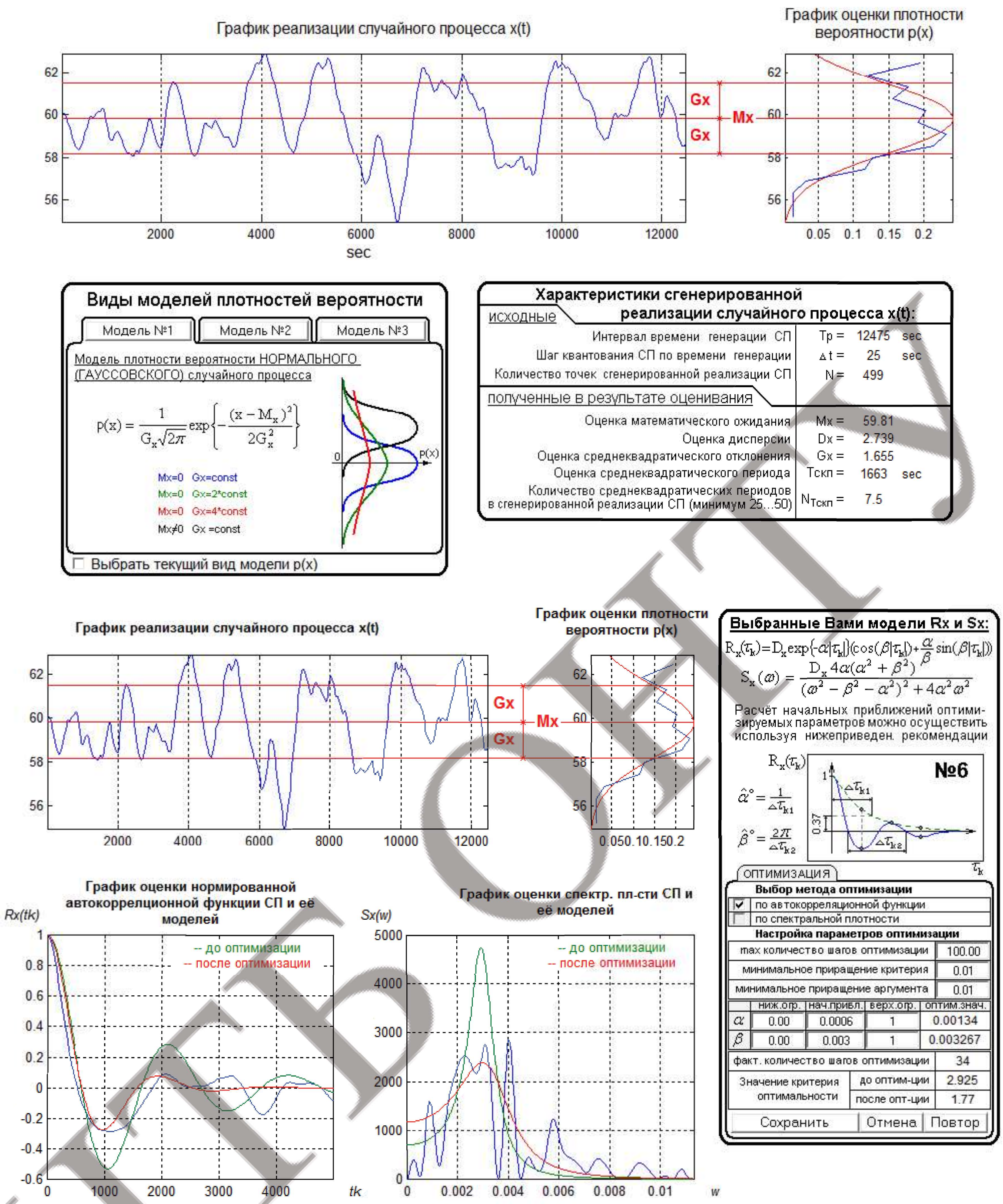


Fig. 20 – The results of modeling uncontrolled perturbations with the calculated parameters of the forming filter

Let's estimate accuracy of reproduction of parameters in model. The results show that the reproduction error σ_f, α i β less than 5%, hence the accuracy of the model of uncontrolled perturbations is sufficient.

3.5. Parametric synthesis and analysis of ACS base structure

The coordinate diagram of the drying process in the drying chamber is shown in Fig. 3. According to it, the block diagram of the ACS will look like Fig. 21.

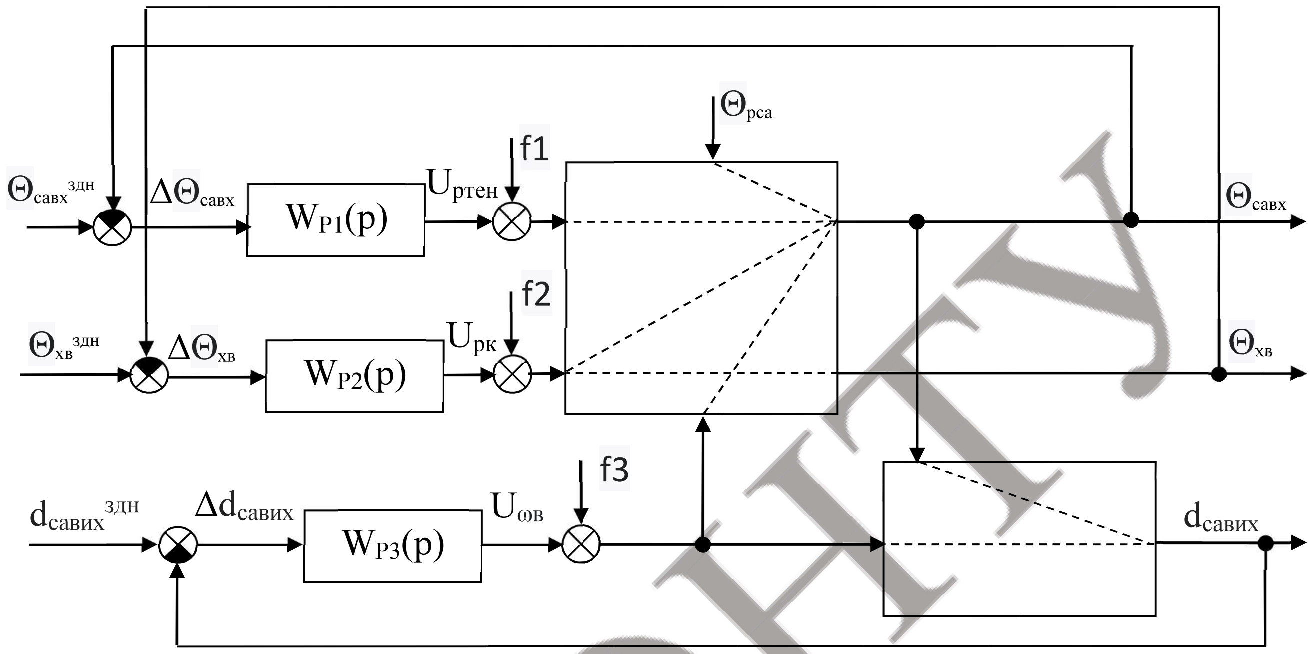


Fig. 21 – Block diagram of the ACS control of the moisture content of the drying agent of the basic structure

In the picture:

$U_{хв}$ – the position of the cold water temperature regulator;

$U_{ртен}$ – the position of the temperature regulator of the drying agent;

$U_{ωв}$ – the position of the regulator of the moisture content of the drying agent;

$Θ_{савх}$ – the temperature of the input drying agent, ^{0}C ;

$Θ_{хв}$ – chilled water temperature, ^{0}C ;

$d_{савих}$ – moisture content of the drying agent, g/кg;

f1, f2 and f3 – vectors of uncontrolled perturbations;

$W_P(p)$, $W_{P2}(p)$ and $W_{P3}(p)$ – transfer functions of temperature controllers for the preparation of the drying agent ;

$Θ_{савх}{}^{здн}$ – the set temperature of the input drying agent, ^{0}C;

$Θ_{хв}{}^{здн}$ – the set value of the cooled water temperature, ^{0}C;

$d_{савих}{}^{здн}$ – the set value of the moisture content of the drying agent, g/кg;

$Δ Θ_{савх}$ – error in adjusting the temperature of the input drying agent;

$Δ Θ_{хв}$ – cooling control error;

$Δd_{савих}$ – error in adjusting the moisture content of the drying agent;

As a control algorithm we choose proportional-integral-differential (PID) control algorithms.

Transfer function of the PID controller

$$W^P(p) = K_p \cdot \left(1 + \frac{1}{T_{IЗ}\, p} + \frac{T_{УП}\, p}{0{,}2 \cdot T_{УП}\, p + 1}\right) \qquad (7)$$

The block diagram of the ACS modeling with the PID controller is shown in Fig. 22, and the structural scheme of modeling OK - in Fig. 23. The results of optimizing the settings of the PID controller are shown in Fig. 24-26.

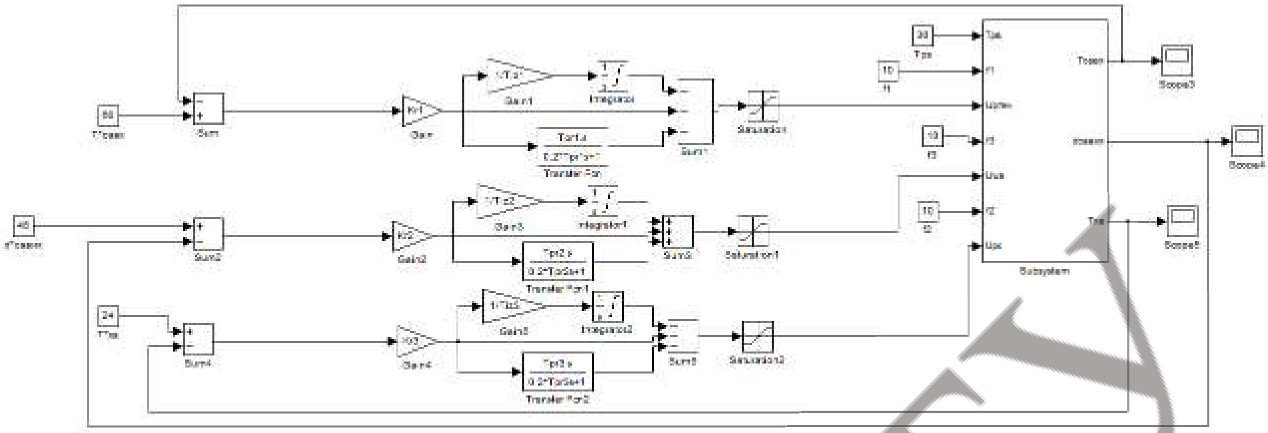


Fig. 22 – Block diagram of ACS modeling with PID controller for optimal parametric synthesis

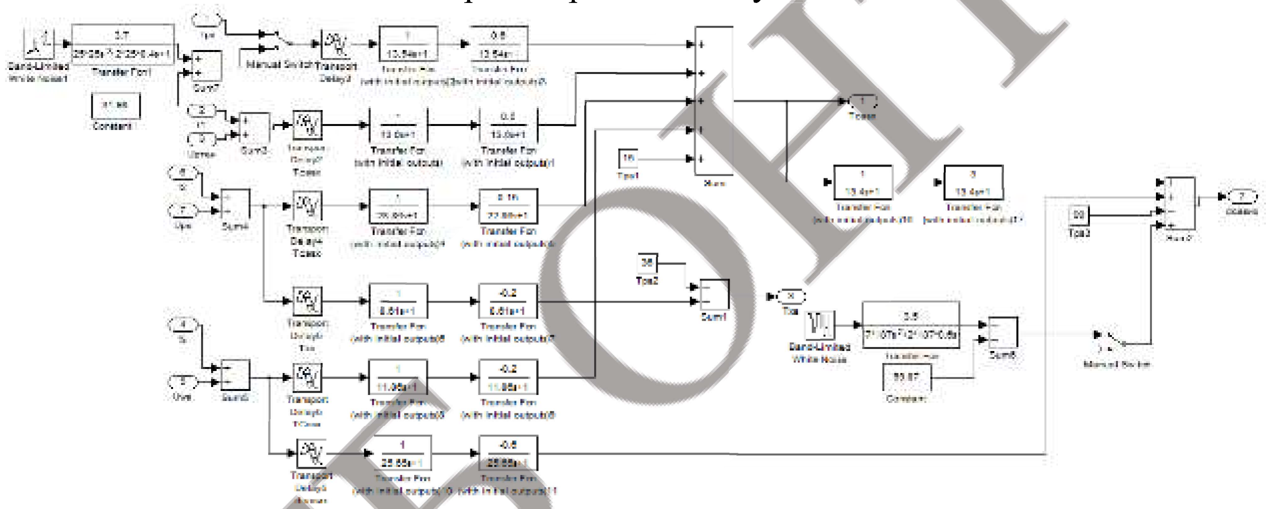
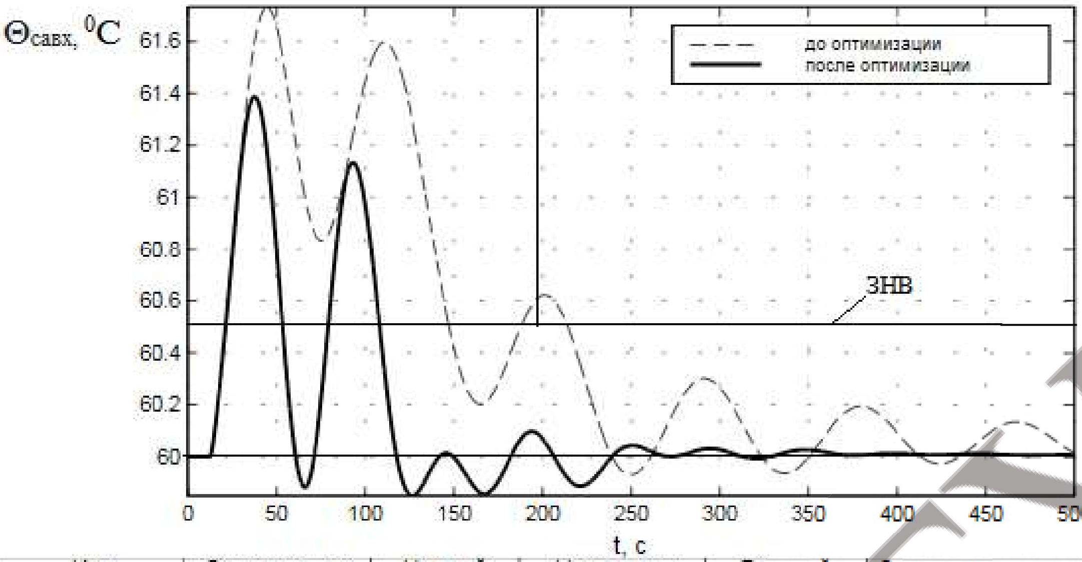
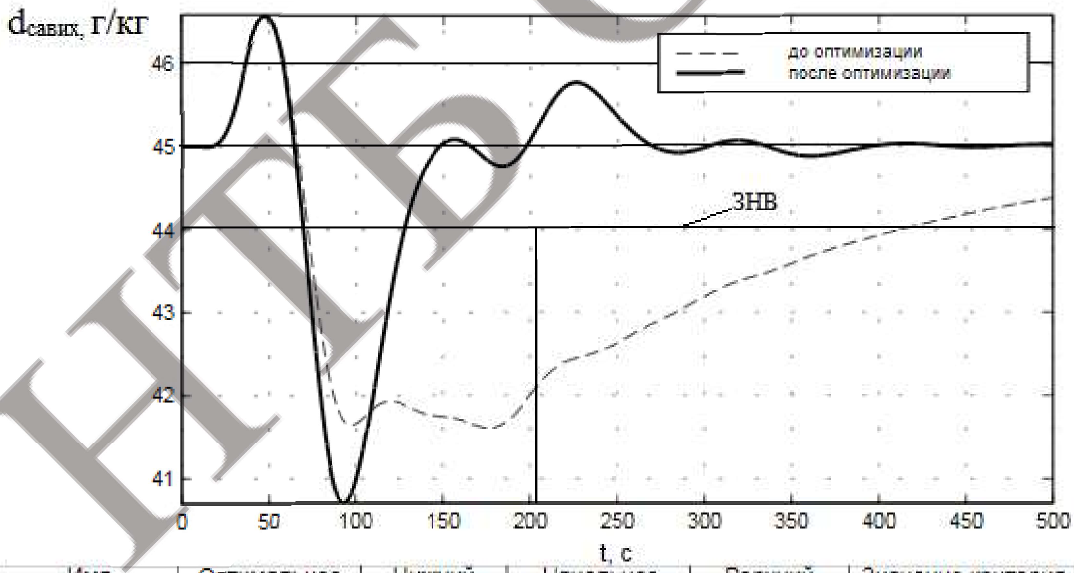


Fig. 23 – Block diagram of the modeling OK PID controller settings



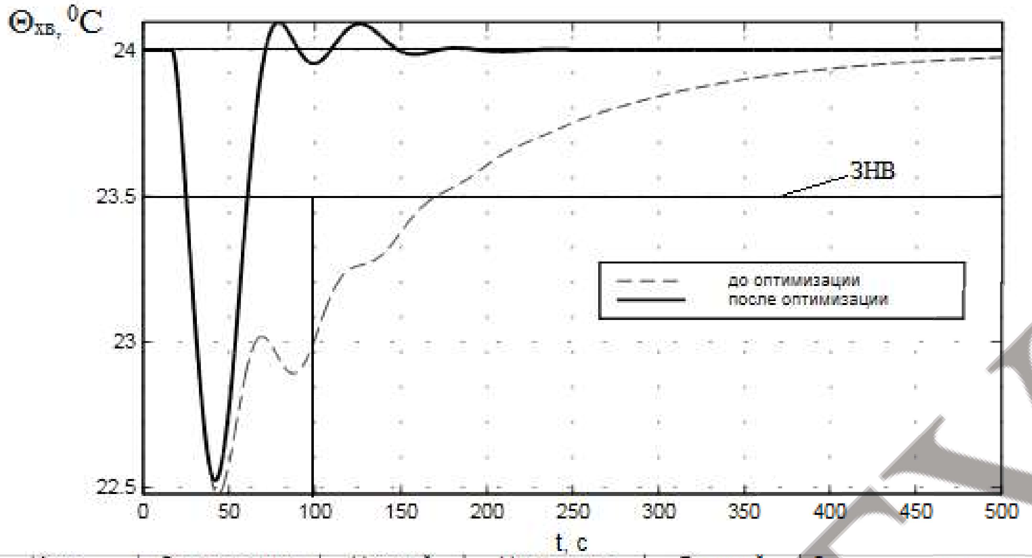
Имя переменной	Оптимальное значение	Нижний предел	Начальное приближение	Верхний предел	Значение критерия оптимальности:
Kr1	3.8986	1	1.86	100	до - 43.2736
Tiz1	26.0378	1	41.8	100	после - 16.1712
Tpr1	12.6204	1	14.63	100	оптимизации.
					Количество шагов процедуры оптимизации:
					максимальное - 1000
					фактическое - 147

Fig. 24 – The results of optimizing the settings of the PID controller by channel «$U_{ртен}$ – $\Theta_{савх}$»



Имя переменной	Оптимальное значение	Нижний предел	Начальное приближение	Верхний предел	Значение критерия оптимальности:
Kr2	-2.9773	-10	-1.14	10	до - 180.1143
Tiz2	34.5902	1	106.08	200	после - 53.4731
Tpr2	15.9415	1	37.13	100	оптимизации.
					Количество шагов процедуры оптимизации:
					максимальное - 1000
					фактическое - 306

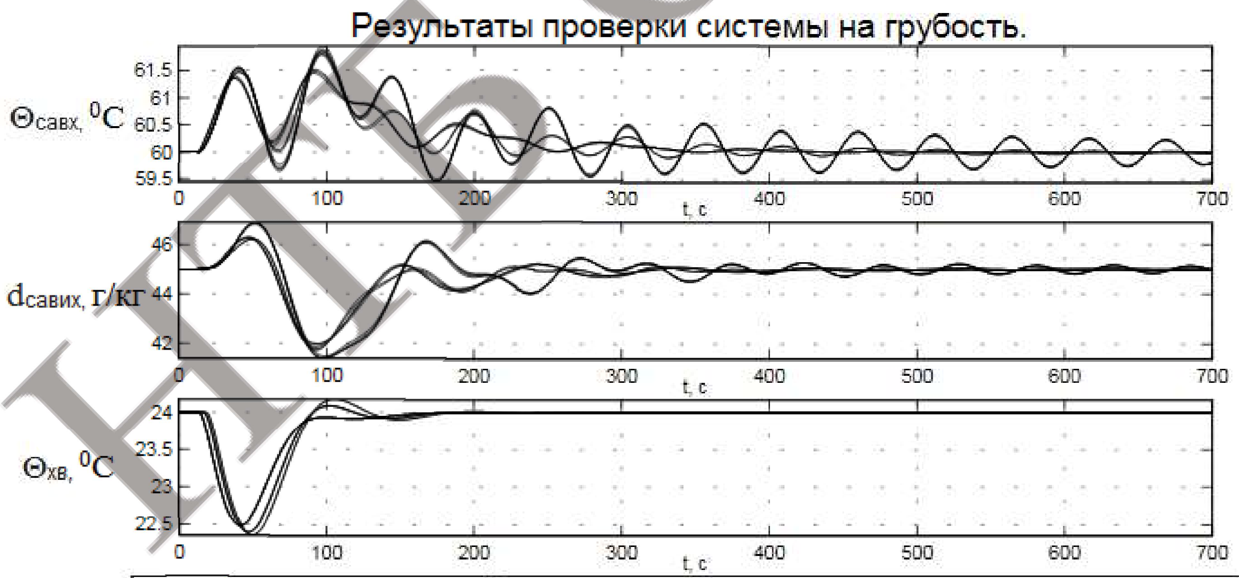
Fig. 25 – The results of optimizing the settings of the PID controller by channel «$U_{ωв}$ – $d_{савих}$»



Имя переменной	Оптимальное значение	Нижний предел	Начальное приближение	Верхний предел	Значение критерия оптимальности:
Kr3	-4.62	-10	-2.44	10	до - 63.3675
Tiz3	18.8539	1	47.08	100	после - оптимизации. 15.8597
Tpr3	8.4817	1	16.48	100	
					Количество шагов процедуры оптимизации:
					максимальное - 1000
					фактическое - 153

Fig. 26 – The results of optimizing the settings of the PID controller by channel «$U_{рк} – \Theta_{хв}$»

Research of ACS with PID-regulator on roughness will be carried out at variation of ± 20% of time of delays OK. The results of the rough analysis are shown in Fig. 27.



Значения параметров объекта управления и значения критерия оптимальности.

1. k1=1 k2=1.1 J=99.1922 k3=0.8 k4=0.9
2. k1=1 k2=1 J=100.1716 k3=0.8 k4=0.9
3. k1=1.1 k2=1.1 J=100.3023 k3=0.8 k4=0.9
4. k1=1 k2=1.1 J=100.3654 k3=1 k4=0.9
5. k1=1.1 k2=1.1 J=101.1132 k3=1 k4=0.9
6. k1=1.1 k2=1 J=150.1303 k3=1.1 k4=1.1
7. k1=1.1 k2=0.9 J=150.4555 k3=0.8 k4=1.1
8. k1=1.1 k2=0.9 J=151.3866 k3=1 k4=1.1
9. k1=1.1 k2=0.9 J=153.6116 k3=1.1 k4=1.1

Fig. 27 – The results of the test ACS with PID-regulator for roughness

As can be seen from the results, the ACS with the PID controller is rough, because in conditions of variation of the parameters of the OK gives convergent transients.

3.6. Structural and parametric synthesis and analysis of ATS increased dynamic accuracy

The main way to increase the dynamic accuracy of the considered ACS is to build an ACS invariant to the action of controlled perturbation. Accordingly, the block diagram of the ACS will look like Fig. 28.

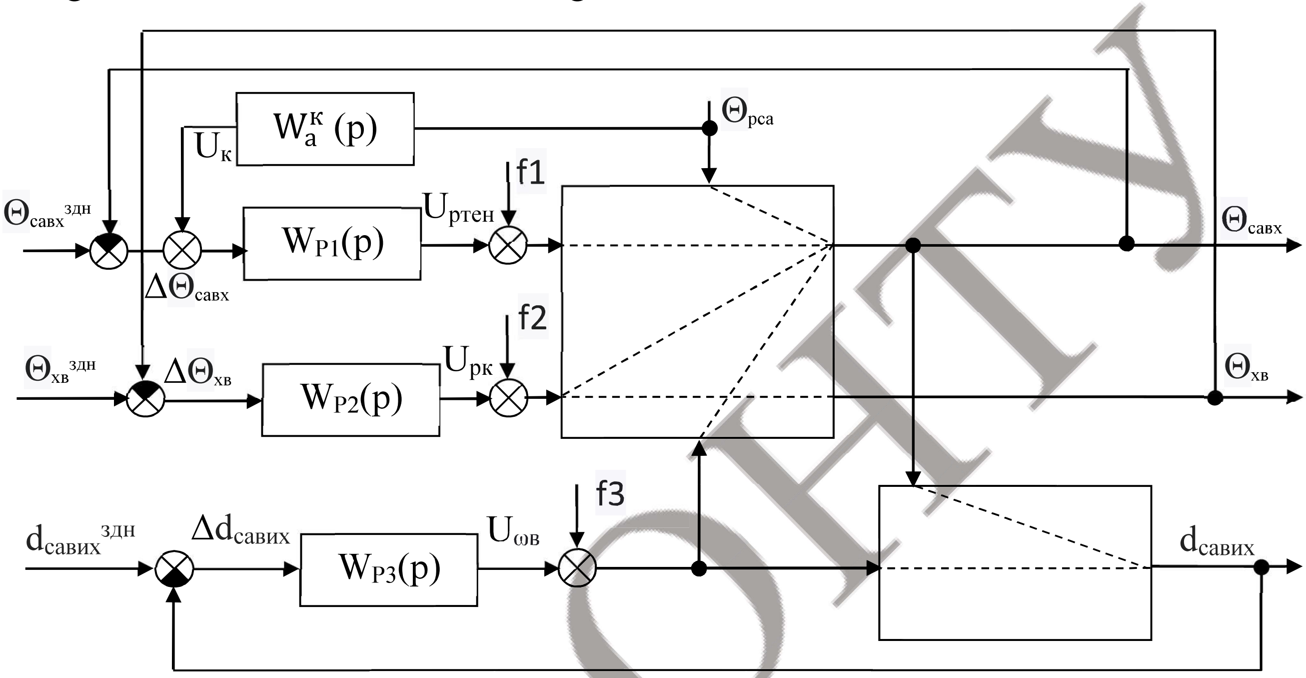


Fig. 28 – Block diagram of ACS of the increased dynamic accuracy

In the diagram $W_a^к(p)$ – transfer function corrective communication.

Before the simulation, a corrective link was calculated and simplified. The block diagram of modeling of ACS of the increased dynamic accuracy is resulted on Fig. 29, and the results - on Fig. 30.

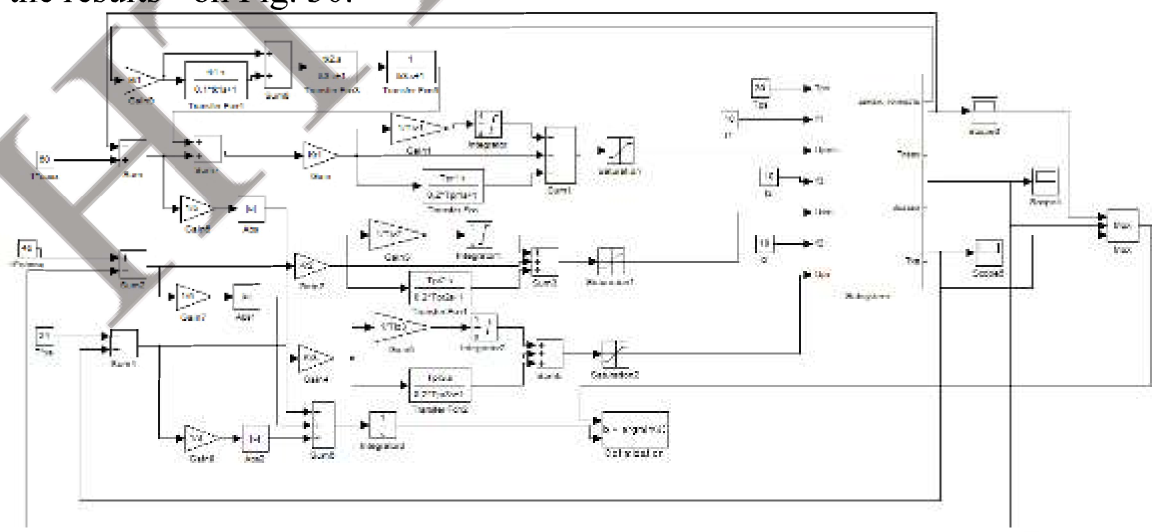
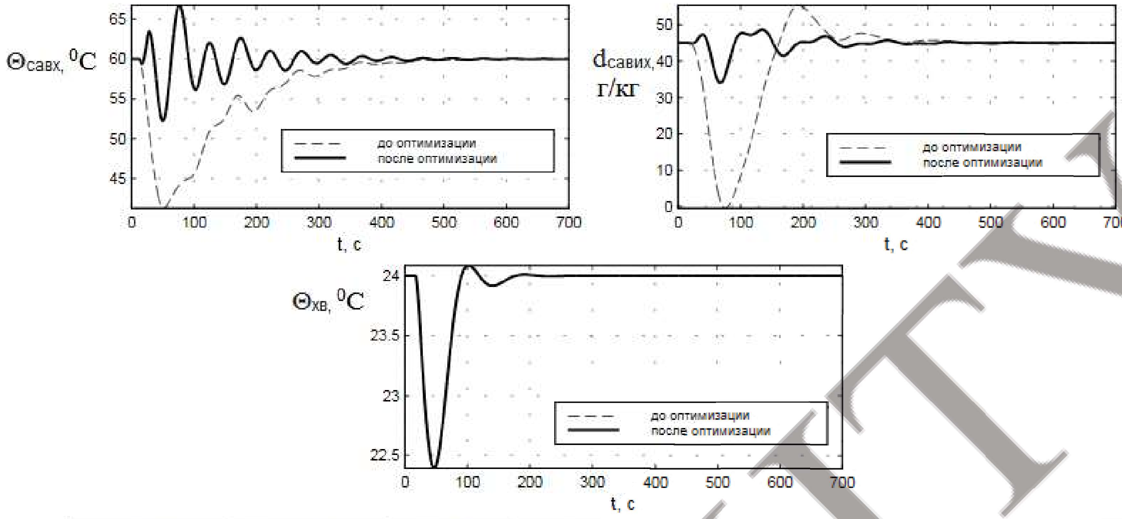


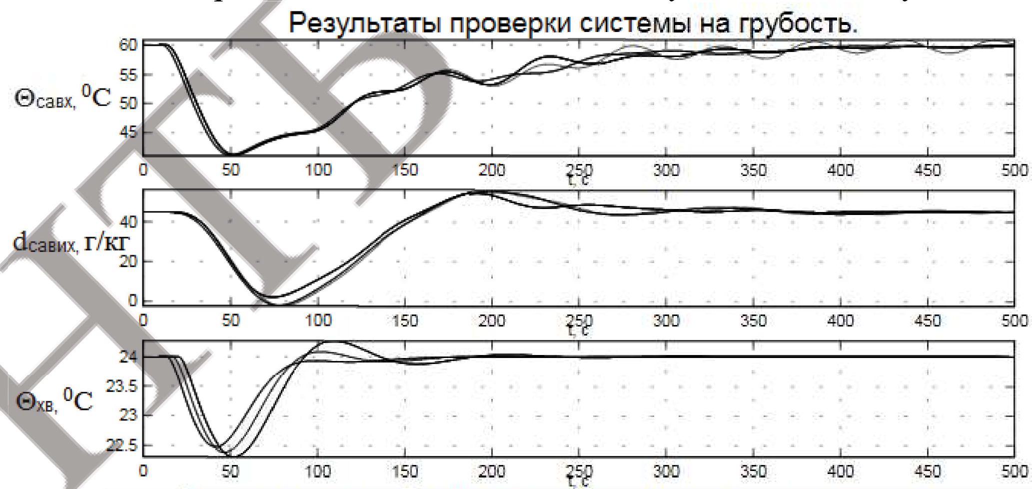
Fig. 29 – Block diagram of ACS modeling increased dynamic accuracy

As in the case of ACS base structure, the study of ACS increased dynamic accuracy for roughness will be carried out with a variation of ± 20% of the delay time OK. The results of the analysis for roughness are shown in Fig. 31.
As can be seen from the results, the ACS of high dynamic accuracy is rough, because in the variation of the parameters of the OK gives convergent transients.



Имя переменной	Оптимальное значение	Нижний предел	Начальное приближение	Верхний предел	Значение критерия оптимальности:
kk1	-2.3047	-20	-1.9	10	до - 1337.3361
tk1	4.0658	-10	15.1	100	после - оптимизации. 275.207
tk2	77.2096	1	83	100	Количество шагов процедуры оптимизации:
tk3	2.2478	1	30.6	200	максимальное - 1000
					фактическое - 106

Fig. 30 – The results of optimizing the parameters of the corrective link as a part of ACS of the increased dynamic accuracy



Значения параметров объекта управления и значения критерия оптимальности.

1. k1=1.1 k2=0.8 J=1284.6977 k3=1 k4=0.8
2. k1=1.1 k2=0.8 J=1284.8532 k3=0.8 k4=0.8
3. k1=1.1 k2=1 J=1285.6952 k3=1 k4=0.8
4. k1=1.1 k2=1 J=1285.7414 k3=0.8 k4=0.8
5. k1=1.1 k2=1.2 J=1287.1114 k3=0.8 k4=0.8
6. k1=0.9 k2=0.8 J=1396.6312 k3=1.2 k4=1.2
7. k1=1.1 k2=1.2 J=1397.2635 k3=1.2 k4=1.2
8. k1=0.9 k2=1 J=1398.0402 k3=1.2 k4=1.2
9. k1=0.9 k2=1.2 J=1399.9153 k3=1.2 k4=1.2

Fig. 31 – The results of the test for the severity of ACS increased dynamic accuracy

IV. RESULTS OF WORK

We will conduct a comparative analysis of transients in parametrically optimal systems by the value of the criterion of optimality and indicators for which the maximum allowable values. Comparison of ACS of basic structure and ACS of the increased dynamic accuracy is given in Fig. 32 and in table 5.

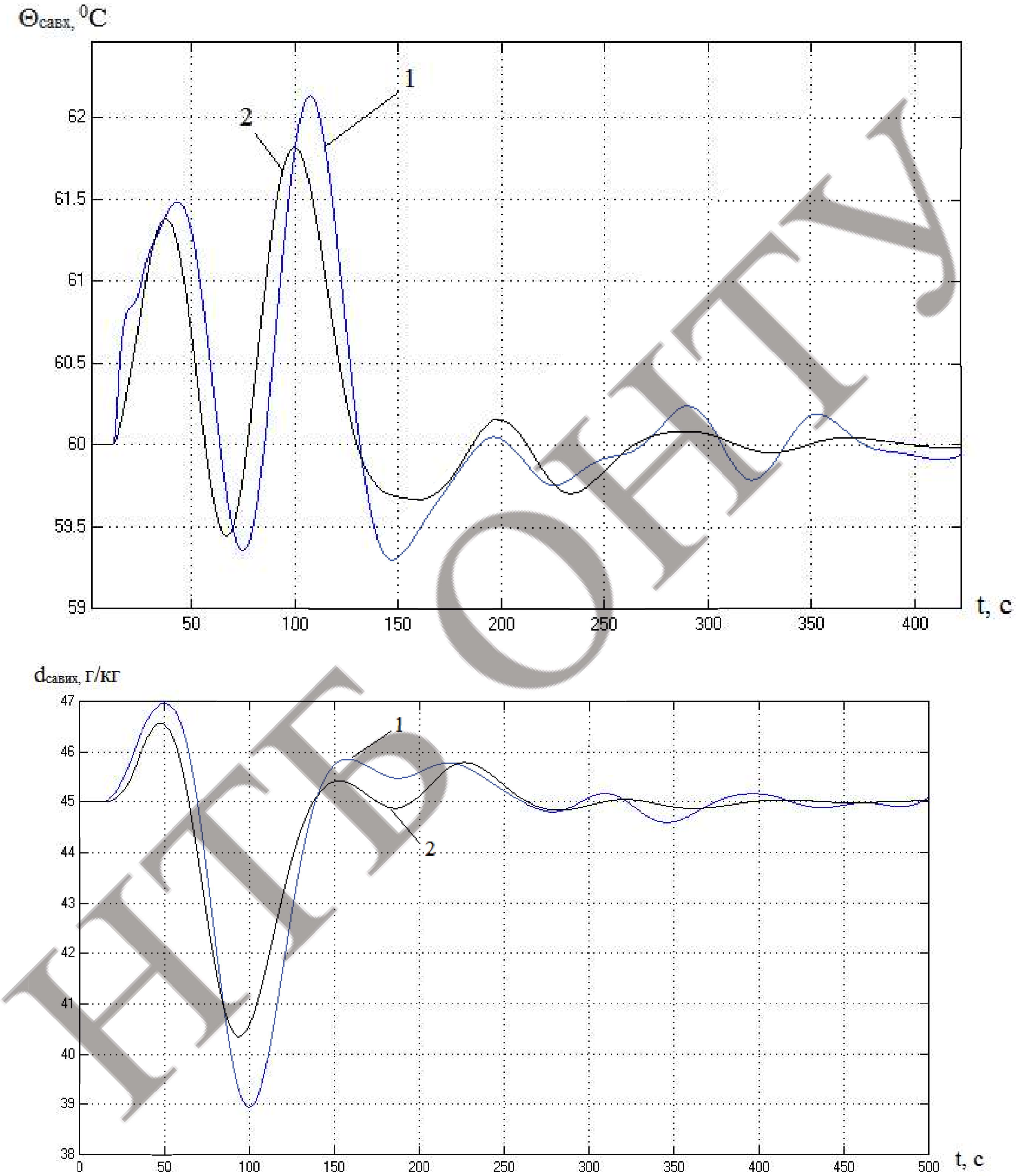


Fig. 32 – Results of comparison of ACS of basic structure (1) and ACS of the increased dynamic accuracy (2)

Table 5 - Comparison of ACS bass structure and ACS increased dynamite accurations

Option ACS	Direct quality indicators			Adjustment time, c			Criterion
	$\Delta\ \Theta_{савх}$ max	$\Delta\ d_{савих}$ max	$\Theta_{хв}$	«$U_{ртен}$ - $\Theta_{савх}$»	«$U_{\omega в}$ – $d_{савих}$»	«$U_{рк}$ – $\Theta_{хв}$»	
ПІД	2	2	1,5	150	150	80	147
ПДТ	1,6	1,3	1,3	100	90	60	51

As can be seen from the results of the comparison of transients, the ACS of increased dynamic accuracy in terms of quality is almost no different from the ACS of the basic structure, except for a slight reduction in the criterion of optimality. But the ACS of increased dynamic accuracy is coarser with a variation of ± 20% of the delay time OK, this can be seen by comparing the results of testing the ACS of the basic structure and ACS of increased dynamic accuracy for roughness (Fig. 27 and Fig. 31).

V. CONCLUSIONS

The scientific work was performed in order to study the possibilities of increasing the energy efficiency of the process of condensation drying of raw materials with energy recovery through the use of a heat pump by improving control algorithms.

The analysis and synthesis of ACS of the increased dynamic accuracy is executed. The synthesis of ACS was implemented and tested using the Simulink emulator Matlab medium.

Increasing the dynamic accuracy of the ACS with PID-regulator gave a significant improvement in the quality of transients and the system became rougher.

ACS invariant to controlled perturbation was chosen as the structure.

VI. LIST OF REFERENCES

1. Киричков В.Н. Идентификация объектов систем управления технологическими процессами. - К.: Выща шк., 1990. - 263 с.

2. Остапчук Н.В. Основы математического моделирования процессов пищевых производств: Учеб. пособие. - К.: Выща шк., 1991. - 367 с.

3. Теория автоматического управления / Учебник под редакцией А.В. Нетушила – М.: Высшая школа, 1983. – 432 с.

4. Теория автоматического управления / Учебное пособие под редакцией А.С. Шаталова. – М.: Высшая школа, 1977. – 448 с.

5. Воронов А.А., Титов В.К., Новогранов Б.Н. Основы теории автоматического регулирования и управления / Учебное пособие. – М.: Высшая школа, 1977. – 519 с.

6. Сборник задач по теории автоматического регулирования и управления под редакцией В.А. Бессекерского. – М.: Наука, 1979. – 512 с.

7. Хобин В.А. Конспект курса лекций по дисциплине «Идентификация и моделирование технологических объектов» для студентов специальности 7.092501 дневной и заочной форм обучения. - Одесса: ОНАПТ, 2003. – 78 с.

8. Хобин В.А. Конспект курса лекций по дисциплине «Теория автоматического управления» для студентов специальности 7.092501 дневной и заочной форм обучения. - Одесса: ОНАПТ, 2007. – 87 с.

9. Баранов Г.Л., Макаров А.В. Структурное моделирование сложных динамических систем. - К.: Наук. думка, 1986. - 272 с.

10. Бессонов А.А., Загашвили Ю.В., Маркелов А.С. Методы и средства идентификации динамических объектов. - Л.: Энергоатомиздат, 1989. - 280 с.

11. Куликов Е.И. Методы измерения случайных процессов. – М.: Радио и связь, 1986. – 272 с.

12. Тихонов В.И., Хименко В.И. Выбросы траекторий случайных процессов. – М.: Наука, 1987. – 304 с.

13. Шалыгин А.С., Палагин Ю.И. Прикладные методы статистического моделирования. – Л.: Машиностроение, 1986. – 320 с.

14. Анализ и оптимальный синтез на ЭВМ систем управления / Под редакцией А.А. Воронова и И.А. Орурка. – М.: Наука, 1984 – 344 с.

15. Белова Д.А., Кузин Р.Е. Применение ЭВМ для анализа и синтеза автоматических систем управления. – М.: Энергия, 1979. – 264 с.