Розглянуто можливість використання штучних газів в якості палива замість природного газу для енергетичних барабанних котлів. Запропоновано технічні рішення для автоматичного управління як одним барабанним котлом, так і групою, що працює на загальний паропровід. Рішення засновані як на використанні додаткових технічних засобів, так і багатовимірних оптимальних алгоритмів керування

Ключові слова: барабанний котел, автоматична система управління, штучні горючі гази, технологічна ділянка

Рассмотрена возможность использования искусственных газов в качестве топлива вместо природного газа для энергетических барабанных котлов. Предложены технические решения для автоматического управления как одним барабанным котлом, так и группой, работающей на общий паропровод. Решения основаны как на использовании дополнительных технических средств, так и многомерных оптимальных алгоритмах управления

Ключевые слова: барабанный котел, автоматическая система управления, искусственные горючие газы, технологический участок

IMPROVEMENT OF THE CONTROL SYSTEM OVER DRUM BOILERS FOR BURNING COMBUSTIBLE ARTIFICIAL GASES

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1. Introduction

According to expert estimates of the world economy growth, the demand for energy resources may grow by 36 % from 2011 to 2030 [1]. Key factors driving the increase in energy consumption will include the planet's population growth (up to 8.3 billion by 2030) and the rise in global GDP (twice compared to 2011). Owing to rapid industrialization and urbanization of the low and middle-income countries, they will account for 70 % of the world GDP growth and for over 90 % of the increase in world demand for energy. A logical increase in the energy demand, that is in proportion to the GDP growth, will be limited by a continuous improvement of the efficiency of its use. Reduction in the energy intensity of production will be achieved by utilizing renewable energy resources, shale energy, and the new improved technologies for the production of industrial products and raw materials processing [2].

Under conditions when the price of conventional energy resources in global markets experiences sharp fluctuations and access to them can be restricted, it is required, first of all, to consider the geographical position and the availability of a certain type of energy resources. An implementation of low-cost activities with a fast payback period might become a promising direction in the development of energy sector. This will make it possible, without attracting significant funds, in the shortest possible time, to reduce fuel and electricity consumption. For example: employing new structural schemes and automated control systems at steam generators that are at operation today. Given this, there is a possibility to use as fuel combustible artificial gases without substantial modernization of equipment.

The artificial gases, which are produced from solid fuel, include coke, shale, generator and blast-furnace gases. In most cases, these gases are a byproduct of chemical or metallurgical production and economically disadvantageous to be transported over long distances as they possess low calorific value (Table 1).

Table 1

Density and calorific value of artificial gases

Gas	Density, kgf/m³	Calorific value, MJ/m³
Coke	0.342	17.58
Shale	1.040	13.85
Generator, mixed	1.141	5.15
Generator, obtained at steam-oxygen blowing under pressure	0.576	15.70
Blast-furnace	1.283	4.10
Gas, obtained by low-temperature carbonization from bituminous coal	0.620	31.90

Therefore, it is a relevant direction in the development of thermal automatics to study the possibility of improving existing control systems for the combustion of cheap artificial gas.

2. Literature review and problem statement

When addressing the issue of burning a fuel with variable chemical composition, one can point to several main directions: structural, technological, and analytical. The world's leading developers of the technologies of combustion of synthesis gases are Siemens (Germany), General Electric (USA), and Mitsubishi Heavy Industries (Japan), which propose burning artificial gases in gas-turbine plants (GTP) with improved combustion chambers [3]. Also considered is the possibility of modernizing the burners themselves for changing the torch geometry, where the burner design employs the effect of interaction between gas jets with an incident transverse air flow [4].

Another approach involves a modification of the fuel itself – dilution of the synthesis gas with nitrogen, steam, or combustion products [5]. All of this greatly enhances the power of GTP. That is, an increase in the consumption of combustion products through the gas turbine and an elevated steam-turbine part's power occurs owing to the increased mass flow rates of flue gases through a heat recovery boiler. It is also possible to add to the low-quality fuel combustion activators (anaclarid) with a simultaneous improvement of the system for fuel supply to a furnace [6]. The countries with a developed agrarian sector utilize joint combustion of fossil fuels and biomass [7].

Economic effect can also be achieved through the development of an individual technological circuit, preparation and delivery of artificial gas to the place of combustion. Here also belong the intermediate heat selection techniques to produce electricity. The circuits that imply not the final unit of artificial gas combustion but rather from the intermediate point of its partial cooling [8]. If there are multiple consumers of gaseous fuels, one may allocate heat load among a group of boilers, which work on a common steam pipe, depending on the caloric value of the combusted gas. Underlying this solution is the minimization of an objective function that takes into account the probability of equipment failure and maximum efficiency of its application [9].

Analytical approach is associated with determining the chemical composition of a combustible gas by using a mathematical model of the fuel combustion process with known qualitative composition [10]. Further improvement of the mathematical method for determining the composition of a combustible gas makes it possible to soften restrictions on the fuel used and to implement this idea in the form of a technical device [11]. Such an approach would enhance the existing systems of nonlinear control over a boiler unit in which extreme regulator analyzes the current consumption of fuel, air, and steam, and determines the optimal ratio of gas-air mixture components [12].

3. The aim and objectives of the study

The goal of present research is to determine a technical possibility to expand (increase) the range of control action of the automated control system over thermal load with a signal by heat. Such control system must provide supply of the required amount of artificial gas to the burners when the throughput of the regulator is limited.

To accomplish the set goal, the following tasks have been selected:

– to determine the effect of throughput of the regulator on the consumption of artificial gas on the burners;

– to define a dependence for the calculation of a communication device between the heat load ACS and the control system of gas compressor;

– to synthesize a multidimensional optimal control system over a group of drum boilers that burn artificial gas and generate steam to a common steam line.

4. Materials and methods to study control system for a technological section of steam generation

4. 1. Determining the effect of artificial gas composition on the throughput of the regulator

Steam drum boilers are widely used in thermal power plants, industrial and heating boiler rooms. To maintain the specified steam production, a standard automated control system (ACS) over thermal load is used (Fig. 1). A task of the thermal load ACS is to maintain the set pressure of superheated steam when a drum boiler operates under controlling mode, or the specified consumption of superheated steam when the boiler is running under basic mode. A thermal load ACS has two modifications. The first one is with a signal on fuel consumption when the burners are fed with liquid or gaseous fuel with a constant calorific value. The second one is with a signal on heat release in the combustion chamber when using a solid fuel, or qualitative composition of the liquid or gaseous fuel is not constant [13].
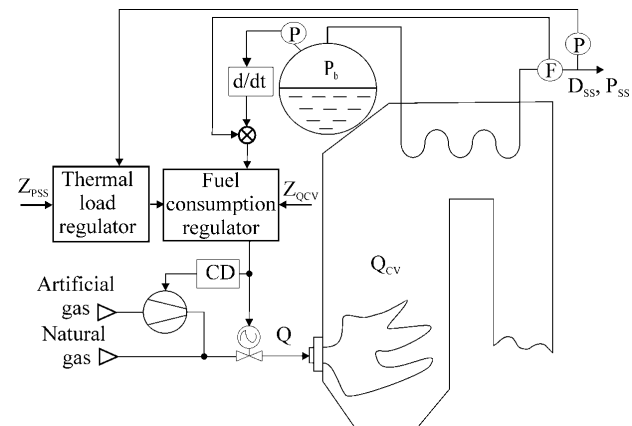

Fig. 1. Structural diagram of the thermal load control with a signal on heat

The capacity of a thermal load ACS with a signal on heat release to compensate for the in-flow perturbations with specific fuel combustion heat is limited by the throughput of the regulator, which does not exceed 20 % of the nominal natural gas flow rate. It is necessary to also take into account the density and calorific value of artificial gases, which may differ from the similar properties of natural gas ($\rho_{NG} = 0.68 \div 0.85$ kg/m³, $Q_{LHV}^{NG} = 28 \div 46$ MJ/m³) in both larger and smaller side (Table 1).

Maximum volume gas flow rate, reduced to normal conditions (P=1.033 kgf/cm², Θ=0 °C), through the regulator (R) is determined from equation

$$Q_{\max} = 535 K_{\vartheta}^{\max} \sqrt{\frac{\Delta P_R P_2}{\rho T_1 k'}}, \qquad (1)$$

where $K\upsilon_{\max}$ is the maximum throughput of R, ΔP_R is the pressure differential on R, P_2 is the pressure of medium after R, ρ is the density of gas, T_1 is the temperature of gas before R, k' is the compressibility factor.

Because $K_{\upsilon}^{\max}$, P_2, T_1, k' over the operation of boiler equipment practically do not change, then equation (1) can be written in the form

$$Q_{\max} = K_R \sqrt{\frac{\Delta P_R}{\rho}}, \qquad (2)$$

where K_R is the constant coefficient, which determines the maximum gas flow rate to the burners depending on differential pressure on R and gas density.

Given the calorific value of gas Q_{LHV}, heat release in the combustion chamber will be determined from equation

$$Q_{CV} = Q_{LHV} Q_{\max} = Q_{LHV} K_R \sqrt{\frac{\Delta P_R}{\rho}}. \qquad (3)$$

If we accept that gas pressure in the gas pipeline is kept constant, then heat release in the combustion chamber at fully open R will depend only on the density of gas and its calorific value. The ratio of natural gas heat release Q_{CV}^{NG} to the heat release of artificial gas Q_{CV}^{AG} allows us to determine the potential for using the existing boiler equipment for the combustion of alternative gaseous fuel

$$\frac{Q_{CV}^{NG}}{Q_{CV}^{AG}} = \frac{Q_{LHV}^{NG}}{Q_{LHV}^{AG}} \sqrt{\frac{\rho_{AG}}{\rho_{NG}}}. \qquad (4)$$

Table 2 gives results of the calculation of ratio (4) for the average density (ρ_{NG}=0.765 kg/m³) and the average natural gas heat release (Q_{LHV}^{NG}=37 MJ/m³).

Table 2

Ratio of natural gas heat release to the artificial gas heat release based on calculation results from formula (4)

Gas	$\dfrac{Q_{CV}^{NG}}{Q_{CV}^{AG}}$	Exceeding the throughput, %
Coke	1.41	21
Shale	3.11	191
Generator, mixed	8.77	757
Generator, obtained at steam-oxygen blowing under pressure	2.04	84
Blast-furnace	11.7	1050
Gas, obtained by low-temperature carbonization from bituminous coal	1.04	–

Results of the calculation show that the gas, which is obtained by low-temperature carbonization of bituminous coal, can be used instead of natural gas. In this case, the additional opening of the regulator to ensure nominal steam generation will make up 4 %. One of the ways to increase capacity of the regulator throughput is to increase the pressure differential on it. This can be achieved if artificial gas is fed to the burners using a compressor. The compressor, by increasing the pressure of gas before a fully open regulator, increases its consumption and compensates for its low calorific value and high density.

4. 2. Mathematical description of the control object

The examined technological section consists of a compressor and a pipeline for artificial gas, a drum boiler, and a steam line. Natural or artificial gas passes through the regulator and burns in the combustion chamber. The adjustable parameters for this section are: pressure of superheated steam P_{SS} and heat release in the furnace chamber Q_{CV}. Controlling influence is the position of R on the consumption of gaseous fuel h_R, or the number of rotations of a compressor's drive n. Perturbing influences are the calorific value of fuel (internal perturbation) and the thermal load of steam user (external perturbation). To control a technological section, a two-contour control system is applied with a stabilizing fuel flow regulator and an adjusting regulator of the superheated steam pressure (Fig. 1).

Based on studies that consider a probabilistic approach to the distribution of heat load [9], and research into control over of cogeneration plant [14], it is possible to record a system of linear differential equations with deviations for the controlled section. The system of equations also takes into account the features of the chosen regulation technique. Equation for a gas compressor and a section of the gas pipeline from it to the combustion chamber:

$$T_{GP} \Delta \dot{Q}_{AG} + \Delta Q_{AG} = T_K \Delta \dot{n} + k_K \Delta n, \qquad (5)$$

where T_{GP} is the inertia of the gas pipeline, k_k is the transfer coefficient between the number of rotations n and volumetric consumption of artificial gas Q_{AG}.

Equation of heat release in the furnace chamber for natural and artificial gas:

$$\Delta Q_F = Q_{CV}^{NG} K_R \Delta h_R + Q_{CV}^{AG} \Delta Q_{AG} + Q_{AG} \Delta Q_{CV}^{AG}. \qquad (6)$$

Equation of heat transfer in the furnace chamber to a steam-water mixture in the screen heating surfaces:

$$T_T \Delta \dot{Q}_T + \Delta Q_T = k_F \Delta Q_F, \qquad (7)$$

where T_T is the inertia of the heat transfer process, k_F is the coefficient of heat transfer from the torch to the screen heating surfaces.

Equation for the steam pressure dependence in boiler drum P_b on the amount of heat, obtained by a water steam mixture, and steam flow rate to the consumer D_{SS}:

$$T_{SG} \Delta \dot{P}_b = k_T \Delta Q_T + k_D \Delta D_{SS}, \qquad (8)$$

where T_{SG} is the inertia of the steam generation process in a boiler drum, k_T, k_D are the transfer coefficients between heat absorption and thermal load, respectively.

Equation for a steam pipe from the boiler drum to the consumer:

$$T_{SS} \Delta \dot{P}_{SS} + \Delta P_{SS} = k_{SS} \Delta P_b, \qquad (9)$$

$$T_{SS} \Delta \dot{D}_{SS} + \Delta D_{SS} = k_{SD} \Delta P_b, \qquad (10)$$

where T_{SS} is the inertia of a steam pipe, k_{SS}, k_{SD} are the transfer coefficients between a change in the pressure in the boiler drum and a change in the pressure and flow rate of the superheated steam, respectively.

Based on equations (5)–(10), it is possible to construct a parametric schematic of the controlled object (Fig. 2). The schematic shows that the major uncontrollable perturbation is a change in the calorific value of artificial gas ΔQ_{CV}^{AG} and its density $\Delta\rho_{AG}$.
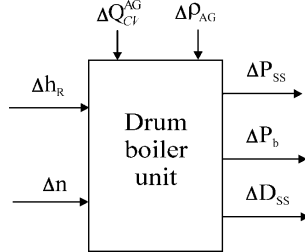

Fig. 2. Parametric schematic of the controlled object

Perturbation due to a change in the caloric value of fuel is eliminated in a standard ACS by the fuel regulator that employs a signal on heat in the negative feedback

$$\Delta Q_{CV}^{CONTR} = C_{AC}\frac{dP_b}{dt} + \Delta D_{SS},$$

where C_{AC} is the constant coefficient characterizing the mass accumulating capacity of a steam-water mixture and metal of the boiler's evaporation unit [11].

4. 3. Determining a structure of the communication device and structural circuit of control

The improved thermal load ACS of a drum boiler must ensure a smooth transition to the supply of artificial gas using a compressor when a fuel regulator maximally opens up the regulator. In this case, controlling signal from the fuel regulator, in accordance with which the displacement of the regulator previously occurred, must be changed. A change in the controlling signal using CD should not lead to a significant change in the properties of the object along the regulatory channel.

The ratio of two transfer functions that describe a change in the heat release in the furnace chamber depending on the location of R and performance efficiency of the compressor defines the type of a communication device. The resulting solution is therefore true when ACS manages only one drum boiler (Fig. 1).

$$W_{CD}(S) = \frac{Q_{CV}^{NG}K_R(T_{GP}S+1)}{Q_{CV}^{AG}K_K\left(\dfrac{T_K}{K_K}S+1\right)}. \tag{11}$$

Given the low inertia of gas compressors and the section of a gas pipeline from the compressor to the burner, a transfer function of CD (11) can be simplified:

$$W_{CD}(S) \approx \frac{Q_{CV}^{NG}K_R}{Q_{CV}^{AG}K_K}. \tag{12}$$

The simplified transfer function of CD is a proportional link. However, the existence in expression (12) of calorific values of natural and artificial gases imposes the following

constraints on the operation of such an ACS. The burners should be fed with only one type of artificial gas, or ACS should be supplemented with a device that determines chemical composition of the fuel combusted [11].

In the case when a technological section includes two and more drum boilers, part of them is set to the basic operation mode (boilers generate a constant amount of superheated steam). Another part works under regulating regime, maintaining constant pressure of the superheated steam in the common steam pipe [13]. The application, in this case, of an individual gas compressor for each boiler is not economically feasible. The solution might be to use one productive compressor, which should increase pressure of artificial gas in the common gas pipeline (Fig. 3). Compressor control mechanism (CCM) monitors the R position of the boiler that operates under regulating mode. In the case of full opening of R, CCM through the appropriate CD changes the setting of the gas pressure regulator in the gas pipeline for a smooth increase in the performance of the compressor. Based on (2), one may determine a functional dependence of changing a task for the gas pressure regulator:

$$\Delta P_R = \rho\left(\frac{Q}{K_R}\right)^2, \tag{12}$$

where Q is the required flow rate of gas to the burners.

Since a rarefaction regulator maintains a constant flue gas pressure in the furnace chamber, ΔP_R at fully opened R will depend only on the gas pressure in the gas pipeline. Therefore, the desired dependence for assigning the signal to the pressure regulator will equal:
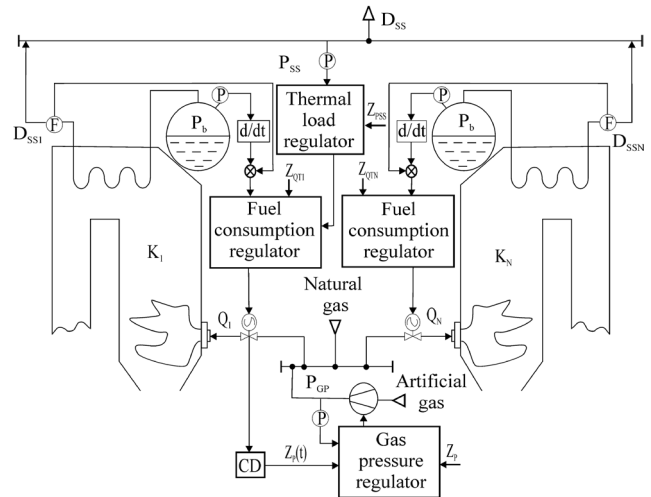
$$Z_P(t) = kQ^2(t). \tag{12}$$

Fig. 3. Schematic of ACS for a group of boilers

An increase in pressure in the common pipeline will make it possible to restore synchronously the overall performance of boilers, which operate under basic mode.

4. 4. Results of study of the synthesis of a multidimensional control system for a group of drum boilers that operate on artificial gas

A modern approach to the concept of automated control is related to considering a control object in the form of a complex dynamic system with a certain number of inputs and outputs. Calculation of the controlling influence is

performed with taking account of direct and cross linkages between controlling influences and adjustable parameters. In order to solve a problem on the multidimensional optimal control, in accordance with the specified quality criterion, one requires a mathematical model that would describe behavior of the group of N drum boilers connected to a common steam line. Linear differential equations (6)–(10) form subsystems of mathematical model with sets of matrices $\{A_i, B_i, C_i, D_i\}$. Numerical values of transfer coefficients and time constants of each subsystem account for the individual thermal and structural characteristics of each drum boiler. To obtain a generalized mathematical model, it is necessary to take into account a combined effect of change in the position of a separate regulator on the gas flow rate to other boilers.

$$\Delta Q_{AG} = K_{CD}\Delta h_{R_{N(i)}}, \tag{13}$$

where K_{CD} is the coefficient of mutual influence of the control valves on the gas flow rate to each boiler, and steam generation by an individual boiler on the total pressure in a steam line

$$T_{SS}\Delta \dot{P}_{SS} + \Delta P_{SS} = K_{SD}\sum_{i=1}^{N}\Delta D_i, \tag{14}$$

where K_{SD} is the coefficient linking a change in the superheated steam pressure in the common steam line with a change in the steam generation by a separate boiler change ΔD_i.

Thus, a mathematical model for a group of drum boilers, linearized in the vicinity of possible operating modes, can be represented by a system of matrix equations:

$$\begin{cases} \dot{x} = Ax + Bu + Ff; \\ y = Cx, \end{cases} \tag{15}$$

where x is the vector of variables of internal states of the system; y is the vector of controlled parameters (output of the system), u is the vector of controlling influences, f is the vector of basic perturbations, A, B, C, D are the matrices of coefficients of the corresponding dimensionalities. For the synthesis of an optimal control system, which ensures a minimum of the assigned quality criterion of the form

$$J = \int_{0}^{\infty}\left(x^T Q x + u^T R u\right)\mathrm{d}t, \tag{16}$$

where Q and R are the weight matrices, mathematical model (15) is supplemented with a model of measuring transformers in the channels of control of the regulated parameters (inertial link of first order with a transport delay).

For the procedure of synthesis of a digital ACS, a mathematical model is converted from the continuous time scale to the discrete one. After the appropriate transform ($A = e^{A\Delta t}$, $B = A^{-1}(A - I)\overline{B}, F = A^{-1}(A - I)F, C = C$), the system of equations (15) is represented by a system of difference equations with the corresponding period of discreteness Δt:

$$\begin{cases} x_{i+1} = Ax_i + Bu_i + Ff_i; \\ y_i = Cx_i, \end{cases} \tag{17}$$

where x_i is the vector of internal state of the system; y_i is the output vector (a change in the steam consumption ΔD_{SS} for each boiler, a superheated steam pressure variance in the common steam line ΔP_{SS}); u_i is the change in controlling in-

fluence (position of R by the gas flow rate Δh_R and a change in the number of rotations of a compressor's drive Δn); f_i is the perturbation influence (a change in the density $\Delta\rho_{AG}$ of calorific value of gas ΔQ_{CV}^{AG}) (Fig. 2).

There are two possible solutions to the stated problem: a synthesis of the optimal state regulator with a static compensator of the measured perturbation, and the synthesis of optimal regulator with a dynamic compensator of the unmeasured perturbation.

The first solution can be obtained by minimizing the following quality criteria:

$$J = \frac{1}{2}\sum_{i=0}^{\infty}\left\{(z_i - y_i)^T Q(z_i - y_i) + u_i^T R u_i\right\}. \tag{18}$$

Hence, the controlling influence is determined by the following relation

$$u_i = -Kx_i + \overline{K}_f f_i, \tag{19}$$

where $P = LQ_2\left(A, B, C^T QC, R\right)$ is the solution to the Riccati equation of second type, $K = R^{-1}B^T P$ is the regulator matrix, $\overline{K}_f = R^{-1}B^T\left[A - I - BK\right]^{-T}PF$ is the matrix of compensator of the measured perturbation (calorific value of artificial gas and its density) (Fig. 4).
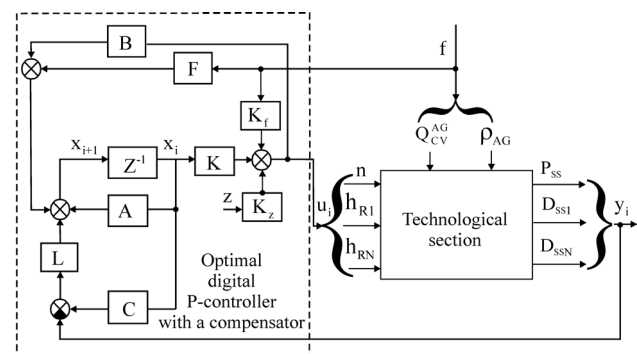

Fig. 4. Structural circuit of the digital ACS with an optimal P-controller and compensators for the measured perturbations and setting

Numerical values for the coefficients of weight matrices Q and R are derived by iterative selection based on the results of modeling a closed-loop ACS.

A state observer matrix is determined by the following relation

$$L = PC^T R^{-1}, \tag{19}$$

where $L^T = LQ_2\left(A^T, C^T, Q, R\right)$ is the solution to the Riccati equation of second type, Q and R are the singular matrices of corresponding dimensionality.

By defining new variables $\Delta u_i = u_i - u_{i-1}$, $e_i = (z - y_i)$ (z is the setting signal), $S_i = \left[e_i, \Delta x_i\right]^T$ and, by minimizing the energy functional of the form:

$$J = \frac{1}{2}\sum_{i=0}^{\infty}\left\{e_i^T Q e_i + \Delta u_i^T R \Delta u_i\right\}, \tag{20}$$

it is possible to obtain a solution to the second problem in the form of the following dependence

$$\Delta u_i = -K_1 e_i - K_2 \Delta x_i,$$

which matches the structure of a discrete PI-controller

$$u_i = -K_1 \sum_{j=0}^{i} e_j - K_2 x_i \quad \text{(Fig. 5)}.$$

Since the equations in increments do not depend on vectors z and f, then, in order to restore the missing coordinates, it is possible to use an ordinary observer of the state

$$\Delta \bar{x}_{i+1} = \bar{A} \Delta \bar{x}_i + \bar{B} \Delta u_i + L(\Delta y_i - C \Delta \bar{x}_i),$$

where L is the matrix of the observer of state of the system,

$$\bar{A} = \begin{bmatrix} 1 & -CA \\ 0 & A \end{bmatrix}, \quad \bar{B} = \begin{bmatrix} -CB \\ B \end{bmatrix},$$

$$\bar{C} = \begin{bmatrix} 1 & 0 \end{bmatrix}, \quad K = \begin{bmatrix} K_1, K_2 \end{bmatrix}.$$
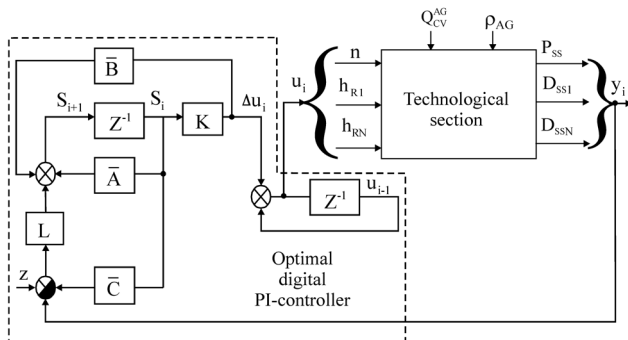

Fig. 5. Structural circuit of the digital ACS with an optimal PI-controller

The implementation of the control circuit with a compensator for the measured perturbations requires a fast-speed technical device, which, based on a chemical analysis, determines the calorific value and density of the gas mixture [11].

5. Discussion of the method for constructing ACS of drum boilers using artificial gases as fuel

The proposed technical solutions are universal for all types of drum boilers that use gaseous fuels. A circuit for controlling a group of drum boilers with a gas pressure regulator in the common pipeline makes it possible to preserve the independence of ACS over a separate boiler. However, oscillatory transient process of fuel pressure stabilization will exert a negative effect on pressure of the superheated steam in the common steam line. A multidimensional ACS lacks this shortcoming, but requires a reliable operation of all measuring transducers and controlling elements. In the process of stabilization of pressure of the superheated steam, a multidimensional ACS directly changes performance efficiency of the compressor. In this case, the R of the boiler, which operates under regulating mode, can be fully open. This position of R is similar to the mode of minimum throttling in a control system over the performance of feeding turbo pumps at AEP [15].

The need for direct measurement of the perturbing influences and the presence of a static error in control is the only drawback of ACS with an optimal multidimensional state regulator and a compensator for the measured perturbations

(Table 3). Integrated quality indicators of the transition processes in the designed ACS for a group of two drum boilers of the GM-50 type were received from the results of mathematical modeling.

In the quality criterion

$$J = \sum_{i=0}^{\infty} y_i^T Q y_i + u_i^T R u_i,$$

weight matrices have the following structure

$$Q = \begin{bmatrix} \dfrac{1}{P_{SS}^2} & 0 \\ 0 & \dfrac{1}{D_{SS}^2} \end{bmatrix}, \quad R = \begin{bmatrix} \dfrac{1}{n^2} & 0 \\ 0 & \dfrac{1}{h_R^2} \end{bmatrix},$$

where P_{SS}=1.2 MPa, D_{SS}=13.9 kg/s, n=100 %, h_R=100 %.

Table 3

Integrated indicators of regulation quality

Quality indicator	With a gas pressure regulator	With a compensator for measured perturbation	Optimal PI-controller
$J = \sum_{i=0}^{\infty} y_i^T Q y_i + u_i^T R u_i$	61.9	31.6	54.2
$J_y = \sum_{i=0}^{\infty} y_i^T Q y_i$	61.8	30.9	54.1
$J_u = \sum_{i=0}^{\infty} u_i^T R u_i$	0.0866	0.730	0.0757

ACS with a compensator for the measured perturbation provides a value of the integrated criterion J that is almost twice less than ACS with an optimal PI-controller. However, the magnitude of part of the integral sum J_u, which takes into account a contribution of the controlling influence, is 9.6 times larger. Thus, in order to compensate for the sudden jump-type perturbations, ACS with a compensator requires a large and rapid change in the controlling action, which must be taken into consideration during its technical implementation.

6. Conclusions

1. It was established that one of the main constraints in the use of cheap fuel without a substantial modernization of the power equipment is the throughput of the regulatory element.

2. We defined the structure of a communication device between a heat load ACS and the control system over a gas compressor. Communication device is a proportional link whose transmission coefficient depends on the calorific value of natural and artificial gases. Therefore, the burners should be fed with only one type of artificial gas, or ACS should be supplemented with a device that determines chemical composition of the fuel burned.

3. It is shown that in terms of integrated indicators, a multidimensional optimal control system over a group of drum boilers has an advantage over a standard thermal load ACS. However, implementing a multidimensional control requires failure-free operation of all measuring transducers and controlling elements.

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