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DEVELOPMENT OF THE SYSTEM OF AUTOMATIC CONTROL OF STEAM BOILERS AT ELECTRIC POWER PLANTS DURING COMBUSTION OF LOW QUALITY FUEL

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Наведено загальний принцип енергозберігаючого керування паровими котлами теплових електростанцій. У функціональні залежності та вихідні моделі керування котельною установкою включені параметри активатора горіння, що поліпшують процес спалювання низькосортних палив. Показано спосіб підвищення точності виміру і регулювання подачі твердого палива в топку котла теплових електростанцій. Розроблено систему автоматичного регулювання подачі активаторів горіння, яка заснована на визначенні якості та кількості подаваного палива. Показано можливий техніко-економічний ефект застосування активаторів горіння

Ключові слова: паровий котел, теплова електростанція, енергозбереження, енергетичні втрати, активатор горіння

Приведен общий принцип энергосберегающего управления паровыми котлами тепловых электростанций. В функциональные зависимости и исходные модели управления котельной установкой включены параметры активатора горения, улучшающих процесс сжигания низкосортных топлив. Показан способ повышения точности измерения и регулирования подачи твердого топлива в топку котла тепловых электростанций. Разработана система автоматического регулирования подачи активаторов горения, основанная на определении качества и количества подаваемого топлива. Показан возможный технико-экономический эффект применения активаторов горения

Ключевые слова: паровой котел, тепловая электростанция, энергосбережение, энергетические потери, активатор горения

1. Introduction

Basic thermal equipment of thermal power plant (TPP) is a steam boiler (SB) [1, 2]. Technological parameters of the SB operation significantly influence specific fuel consumption and prime cost of the manufactured thermal and electrical energy, thus determining performance efficiency of plant as a whole.

An increase in the cost of organic fuel and physical wear of boiler equipment lead to the need for the identification of possible reserves for energy saving, their scientific substantiation and integration of energy-saving algorithms for controlling boiler units into existing ACS of technical process (TP). At the same time, an increase in the volume of the burned solid fuel, the rising cost of its exploration, with simultaneous worsening of quality of obtained fuel, are some of the basic problems of contemporary thermal power industry and coal mining industry. This renders relevant the tasks of considerable increase in the effectiveness of its use both due to the improvement of traditional combustion methods and due to the development of new promising technologies [3–6].

One of such ways implies the creation of energy saving systems of control, which ensure minimum energy losses under all basic modes of operation of power equipment, including the process of combustion of low quality fuels.

A promising trend of increasing the effectiveness of operation of boilers in the process of combustion of low-bustion [7]. Tests of the activators of combustion at power unit No. 1 of Zmievska TPP with capacity of 200 MW and coal fuel consumption of 100 t/h demonstrated that the use of additives-activators on the basis of anaklarid leads to an increase in effectiveness of combustion of low-quality fuel (decrease in losses with mechanical and chemical incomplete burning) and decrease in the consumption of expensive natural gas. The effect is supposedly achieved due to the combustion of flare under the action of the alcohol and hydrogen compounds contained in anaklarid, as well as an increase in temperature in the nucleus of combustion and, accordingly, degree of complete combustion of fuel. During the tests at the power unit No. 1 of Zmievska TPP with the use of the activator of combustion “anaklarid”, an increase in the efficiency coefficient of the power unit reached 3–4 %, which is equivalent to the decrease in the fuel consumption by 4 t/h in the course of generation of the same installed electrical capacity. This opens up great possibilities for essential fuel savings at the coal-dust thermal power plants.

In Ukraine, combined installed capacity of thermal power units is about 20 thousand MW. In this case, an annual economic effect from the introduction of technologies of combustion of low-quality fuels with the use of additives-activators could amount to UAH 4 billion per year [7].

A technical complexity when using activators of combustion is the need for accurate dosing of additives depending on the amount and quality of fuels, which in the existing systems are measured not accurately enough. In connection with it, it is necessary to modernize the system of measuring and feeding solid fuel for the purpose of increasing the accuracy of regulation. It is also necessary to develop the system of power feed of activators of combustion to the boiler furnace, which would maximally consider the quality and amount of fuel.

2. Literature analysis and problem statement

The problems of saving energy at power plants are being explored by the leading scientific schools of Ukraine and of foreign countries. In this direction, a number of effective scientific and technical solutions, which make it possible to substantially increase technical and economic indices of work of power equipment, were obtained. They include methods of improvement of fuel quality [7, 10], improvement of the combustion process [9, 10, 12], the use of up-to-date technologies and design materials [3, 7, 10], improvement of automatic control systems of steam boilers [1, 2, 4, 5, 8, 9, 11].

However, despite successful solutions of a number of problems in the field of energy saving, in the scientific literature there is no statement and solution to the problem of controlling steam boilers directly according to the criterion of minimum energy losses under condition of compliance with the necessary technological limitations. The use of activators of combustion is a new developing trend and there are no systems of feeding activators to the boiler furnace, which consider the quality and the amount of fuel. The activator of combustion as a parameter of a boiler unit is missing in mathematical models of control systems, as well as in the structural and functional schemes of existing ACS. In connection with this, there is the task of creating automatic feed systems of the activator of combustion into the boiler furnace for the purpose of ensuring the maximum effect of their use. These systems must work in parallel with the systems of control and regulation of the supplied fuel, which will make it possible to realize the potential of low-quality fuels with maximum efficiency.

3. The aim and tasks of the study

The purpose of the studies is the development of the system of automated feed of the activator of combustion to the furnace of the boiler of a power plant and the integration of this system into a common ACS of the boiler unit. This will allow increasing the energy effectiveness of operation of a boiler at the combustion of low-quality fuels.

To achieve this aim, it is necessary to solve the following tasks:

– to improve mathematical models of steam boiler as the object of control and models of energy losses in the boiler by including parameters of the combustion in them;

– to develop a functional scheme of automated feed of the activator of combustion to the boiler furnace, which would consider quality and amount of the supplied fuel.

4. Mathematical model of a boiler as the object of control

The automated regulation of direct-flow and drum steam boilers is a complicated scientific and technical problem. The above mentioned is determined by the need for a strict alignment between the supply of feed water and fuel, since the violation of this correspondence considerably affects the intermediate and final values of pressure and temperature of vapor, as well as the majority of technological parameters of a boiler and its energy effectiveness [1, 10].

A vector scheme of a boiler unit as the object of control takes the form, given in Fig. 1 [10].

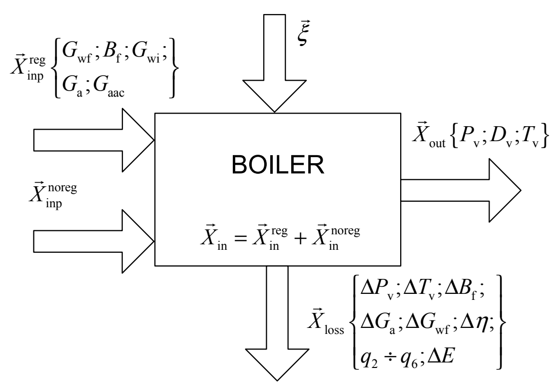


Fig. 1. Vector scheme of boiler the object of control

Vector of the basic input parameters (all of which are regulated) [10]:

$$\vec{X}^{reg}_{inp}\left\{\vec{X}_f;\vec{X}_a\left\{\vec{X}_{a1};\vec{X}_{a2}\right\}\vec{X}_{wf};\vec{X}_{wi};\vec{X}_{aac}\right\}; \quad (1)$$

includes the vectors of parameters of fuel $\vec{X}_f$, and air $\vec{X}_a$ supplied to the boiler (including original air $\vec{X}_{a1}$, mixed up with the fuel and directly supplied to the burners with fuel and air mixture $\vec{X}_{a.term}$, and secondary air $\vec{X}_{a2}$, supplied separately to the upper part of the furnace), feed water $\vec{X}_{wf}$, and water injections $\vec{X}_{wi}$ and additives-activators of combustion $\vec{X}_{aac}$, which can be supplied to the furnace for an improvement in the combustion process.

Each of the enumerated vectors is characterized by four basic parameters: values of mass consumption G, kg/s, pressure P, Pa, temperature T, K, and total energy E, J, that is:

$$\vec{X}_f\left\{B_f;P_f;T_f;E_f\right\}. \quad (2)$$

For solid fuel, parameter of pressure is not included, that is:

$$\begin{cases}\vec{X}_f\left\{B_f;T_f;E_f\right\};\\ \vec{X}_a\left\{G_a;P_a;T_a;E_a\right\};\\ \vec{X}_{wf}\left\{G_{wf};P_{wf};T_{wf};E_{wf}\right\};\\ \vec{X}_{wi}\left\{G_{wi};P_{wi};T_{wi};E_{wi}\right\};\\ \vec{X}_{aac}\left\{G_{aac};P_{aac};T_{aac};E_{aac}\right\}.\end{cases} \quad (3)$$

Vector of the basic (technological) output parameter

$$\vec{X}_{out}=\vec{X}_v\left\{D_v;P_v;T_v;E_v\right\}$$

is characterized, accordingly, by the parameters of vapor flow at the output of the boiler (supplied to the turbine), by mass consumption D_v, pressure P_v, temperature T_v and total energy E_v.

Vectors of two other output parameters of SB – parameters of effluent gases

$$\vec{X}_{eg}\left\{G_{eg};P_{eg};T_{eg};E_{eg}\right\}$$

and slag

$$\vec{X}_{sl}\left\{G_{sl};P_{sl};T_{sl};E_{sl}\right\}$$

is determine characteristics of the gaseous, solid and liquid wastes of the technological process of vapor generation in the boiler and corresponding energy losses with effluent gases E_{eg} with slag E_{sl} (the first of these vectors can be regulated).

The technological process of vapor generation inside SB is characterized by the following basic components:

– the process of fuel combusting in the furnace, which ensures the emission of heat, necessary for transforming water into vapor (part of this thermal energy ΔE_T is lost as a result of the removal through the brickwork of accumulation in the internal elements of a boiler);

– the aerodynamic process of moving the furnace gases in the shaft of a boiler, created by the exhaust fan and ensuring keeping up smooth combustion and removal of combustion products (is characterized by aerodynamic energy losses ΔE_{AD});

– the hydrodynamic process of fluid motion (further – steam and water mixture and vapor) in the hydraulic circuit (heating surfaces), created by the feed pump (is characterized by hydraulic energy losses ΔE_{Hd});

– the process of heat exchange between the furnace gases and the feed water (steam and water mixture, vapor), the consequence of which is the vaporization with the final transformation of feed water into vapor);

– the process of removal of the mixture of solid and liquid combustion products (slag), which is characterized by corresponding energy losses E_{sl}.

Vector of the random disturbing influences in the steady operating mode of SB is characterized by unpredictable changes in amount and quality of fuel (they can be determined by corresponding conditional indices K_f^{amo} and K_f^{qual}) and the environment parameters (temperature T_{oc} and pressure P_{oc} of ambient air); that is

$$\vec{X}_{infl}\left\{K_f^{amo};K_f^{qual};T_{oc};P_{oc}\right\}. \quad (4)$$

Losses in the boiler are determined by ratio [2]:

$$\Delta E=(\Delta E_T+\Delta E_{Hd}+\Delta E_{AD})+E_{eg}+E_{sl}, \quad (5)$$

From mathematical point of view, energy saving control means the minimization of function of the total energy losses (5) [10]:

$$\Delta E_{min}=\min\left\{(\Delta E_T+\Delta E_{Hd}+\Delta E_{AD})+E_{eg}+E_{sl}\right\} \quad (6)$$

with the assigned values of components of vector of the output parameters (parameters of vapor at the output of the boiler):

$$\vec{X}_{out}^{00}=\vec{X}_v^{00}\left\{\vec{G}_v^{00};\vec{P}_v^{00};\vec{T}_v^{00};\vec{E}_v^{00}\right\} \quad (7)$$

and limitations for the consumption of fuel and feed water, maximal for the assigned operation mode:

$$B_f\le B_f^{max}; \quad (8)$$

$$G_{wf}\le G_{wf}^{max}, \quad (9)$$

as well as for the extreme (by conditions of strength, reliability and safety) values of temperature in the furnace:

$$T_{fur}\le T_{fur}^{max}, \quad (10)$$

pressure of feed water:

$$P_{wf}\le P_{wf}^{max} \quad (11)$$

and the value of temperature of feed water at the input of SB, limited by the capacities of the system:

$$T_{wf}\le T_{wf}^{max}. \quad (12)$$

Along with the minimization of direct energy losses in BS (6), two additional adjacent tasks must be simultaneously set and solved:

1. Ensuring maximum heat emission in the furnace at the fuel compression (optimization of the combustion process):

$$Q_{fur}=\left\{Q_{fur}\right\}_{max} \quad (13)$$

with the limitations for the fuel consumption (8) and temperature in the furnace (10).

2. Ensuring maximum heat transfer from the flue gases to steam and water mixture (optimization of effectiveness of using heat, released in the furnace), which comes down to ensuring the maximum value of integral (at the mine volume) coefficient of heat transfer from the flue gases to the steam and water mixture:

$$K_{tt}^{\Sigma}=\left\{K_{tt}^{\Sigma}\right\}_{max}, \quad (14)$$

or in the expression of integral amount of heat, transferred to the boiler:

$$Q_{tt}^{\Sigma} = K_{th}^{\Sigma} \cdot \Delta T_{th}^{0} \cdot S_{tt} = \left\{Q_{tt}^{\Sigma}\right\}_{max}, \quad (15)$$

where ΔT_{th}^{0} is the temperature head between the flue gases and the steam and water mixture, averaged by the heating surfaces; S_{tt} is the summary value of the area of heat transfer of the boiler surfaces.

The difference between the nominal potential heat emission, determined by nominal heating capacity of fuel ($Q_{fur}^{nom} = r_f^{nom} \cdot B_f$, W) and actual heat emission Q_{fur}^{fact} during fuel combustion in the furnace under assigned mode:

$$\Delta Q_{cap} = \Delta E_{cap} = Q_{fur}^{nom} - Q_{fur}^{fact}, \quad (16)$$

where r_f^{nom} is the specific nominal heating capacity of fuel.

The difference between the maximum (theoretical) and actual heat transfer in SB:

$$Q_{tt}^{\Sigma} = \Delta E_{tt}\left(\left\{K_{tt}^{\Sigma}\right\}_{max} - K_{tt.fact}^{\Sigma}\right)\Delta T_{tt}^{cp} \cdot S_{tt}. \quad (17)$$

Summary (integral) energy losses in SB will be determined by the sum of losses (16) and (17) and direct losses (5):

$$\Delta E^{\Sigma} = \left(\Delta Q_{cap} + \Delta Q_{tt}^{\Sigma}\right) + \\ +\left(\Delta E_{T} + \Delta E_{Hd} + \Delta E_{AD}\right) + \left(E_{eg} + E_{sl}\right). \quad (18)$$

Accordingly, the minimization of function of integral energy losses (18)

$$\Delta E_{min}^{\Sigma} = \min\left\{\left(\Delta Q_{cap} + \Delta Q_{tt}^{\Sigma}\right) + \\ +\left(\Delta E_{T} + \Delta E_{Hd} + \Delta E_{AD}\right) + \left(E_{eg} + E_{sl}\right)\right\} \quad (19)$$

in a real time scale of SB operation, with the formulated system of limitations (8)–(13), will represent a formalized mathematical problem of the automated energy saving control of the modes of boiler operation.

In this case, the optimization of the process of fuel combustion (in particular, a reduction of losses at mechanical and chemical incomplete burning) will automatically lead to the decrease in slag amount, and, consequently, to the minimization of losses E_{sl} (temperature of the removed slag can be regulated by the time characteristics of the process of slag disposal), and the intensification of the process of heat transfer will lead to the automatic minimization of energy losses with effluent gases E_{eg}.

The minimization of energy losses, left in function (19), may take the form of totality of separate autonomous optimization problems:

$$\begin{cases} \Delta Q_{cap} = \left\{Q_{cap}\right\}_{min}; \\ \Delta Q_{tt}^{\Sigma} = \left\{Q_{tt}^{\Sigma}\right\}_{min}; \\ \Delta E_{T} = \left\{\Delta E_{T}\right\}_{min}; \\ \Delta E_{Hd} = \left\{\Delta E_{Hd}\right\}_{min}; \\ \Delta E_{AD} = \left\{\Delta E_{AD}\right\}_{min} \end{cases} \quad (20)$$

with a possible introduction to the process of solution of correlation ratios, which consider the most essential interrelations between the separate energy losses and the integration of subsystem of the energy saving control into the common ACS of TP of power units of thermal power plants.

5. The system of feeding fuel and activator of combustion

In the system of control over operating modes of a steam boiler, the accuracy of measuring fuel consumption is becoming increasingly important because the function of ASC of TP is, ultimately, its maximal saving. While the methods of measuring liquid and gaseous fuel consumption are relatively accurate, measuring solid fuel consumption (dust and coal boilers of power units with the capacity of 200 and 300 MW) is a rather complicated task. It is linked to the fact that the existing methods are based on the determination of fuel consumption by the measurable rotation velocity of the dust feeder. However, fuel consumption is determined not only by the rotation velocity, but also by the density of filling the inter-blade space with coal dust, which is not registered in the existing system, but can significantly vary depending on the random processes of state and motion of dust in bunkers (uncontrollable motion and collapse).

The method of measurement, based on simultaneous measurement of rotation frequency and shaft torque of the dust feeder, is proposed for the purpose of increasing the accuracy of measurement of coal dust consumption. The calculation of actual value of dust consumption in the microprocessor computational system is achieved on the basis of differential equation of dynamics of the dust feeder rotor (Fig. 2):

$$J_{df} = \frac{d\omega_{df}}{dt}, \quad (21)$$

where

$$J_{df} = J_{Rot} + J_{dm}; \quad (22)$$

J_{df} is the resulted moment of inertia of the dust feeder, kg·m^2; J_{Rot} is the moment of inertia of the rotor, kg·m^2; J_{dm} is the moment of inertia of the coal dust mass, which is found in the space between the blades, kg·m^2; ω_{df} is the angular velocity of the rotor of dust feeder, rad/s; M_{df} is the shaft torque of dust feeder, N·m.

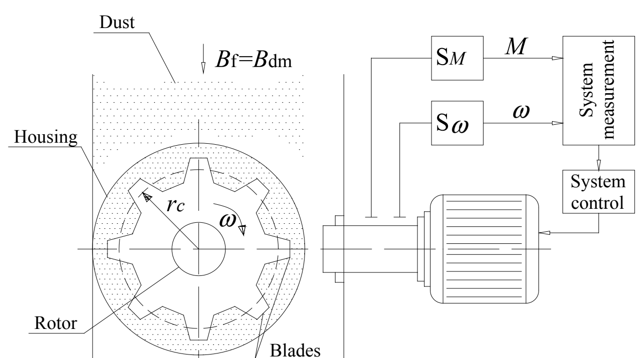


Fig. 2. Structural scheme of blade dust feeder and simplified scheme of its control

At simultaneous parallel measurement of rotation frequency of rotor ω (and differentiation in real time of measuring signal for the purpose of determining angular acceleration $d\omega / dr_C$ and shaft torque), the actual current value of the resulting moment of inertia can be defined in the computing system of the measuring unit from equation (21):

$$J_{df} = \frac{M_{df}}{(d\omega / dr_C)}. \quad (23)$$

Since the value of moment of inertia of rotor J_{Rot} is a constant value (structural characteristic of the rotor), from ratio (22) we can determine the actual current value of moment of inertia of coal dust mass, which is found at the given moment in the space between the blades of the dust feeder

$$J_{dm} = J_{df} - J_{Rot}, \quad (24)$$

which, in turn, is determined by the ratio

$$J_{dm} = m_{dm} \cdot r_C^2, \quad (25)$$

where m_{dm} is the coal dust mass, kg; r_c is the radius of the mean circumference of the inter-blade space, m.

Fig. 3 displays control scheme of the regulator of the dust feeder productivity [11].

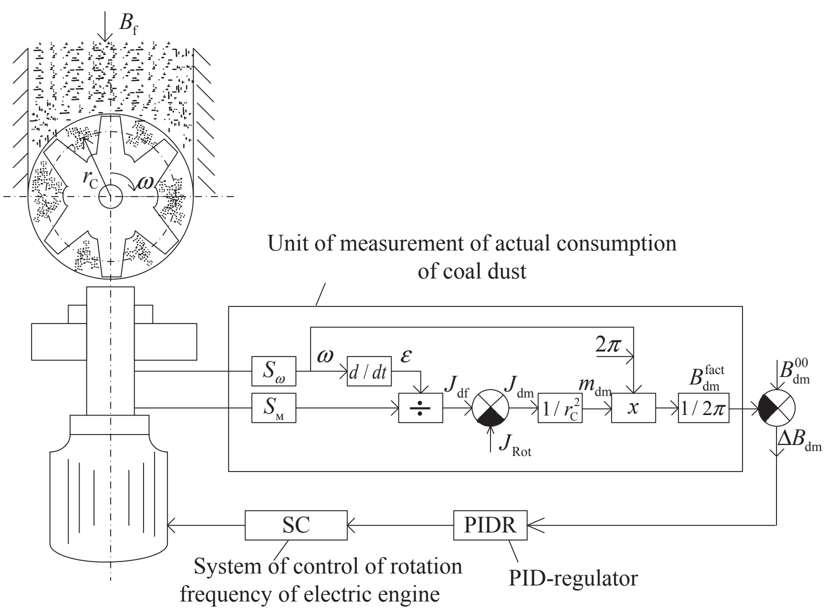


Fig. 3. Control scheme of regulator of dust feeder productivity

From ratio (25), current value of the coal dust mass is calculated:

$$m_{dm} = J_{dm} / r_C^2 \quad (26)$$

and the actual value of consumption of coal-dust fuel

$$B_{dm} = B_f = m_{dm} / t_{1\omega} = m_{dm} \frac{\omega}{2\pi}, \quad (27)$$

where

$$t_{1\omega} = 2\pi / \omega; \quad (28)$$

where $t_{1\omega}$ is the time of one rotation of the dust feeder rotor.

The proposed method for determining the current value of consumption of coal-dust fuel offers broad opportunities for the implementation of SCS of coal-dust steam boilers, since without accurate measurement of fuel consumption it is not technically possible to create and implement actual high-class systems.

One of the effective practical directions is the creation of energy saving SAC of the process of combusting the fuel with the use of additives, which activate the process of combustion. However, the need for precise dosing of additives depending on the amount and quality of the fuel, which can not be sufficiently accurately measured in the existing systems, is the essential technical complexity of using combustion activators. And although the additives themselves are supplied into the furnace evenly over time by the precision hydraulic measuring hoppers, random fluctuations in the amount and quality of fuel, inevitable in actually existing technological systems, are not taken into account. If their amount is insufficient, additives lack positive influence, while in case of an overdose, the process of combustion can even deteriorate (Fig. 4). This factor significantly limits the possibilities of a wide practical application of the technologies described above.

At the same time, at a correct dosage, effectiveness of using activators of combustion can be essential. This is shown in Fig. 5 and in Table 1.

The tests of the combustion activator based on anaklarid, conducted at the power unit of 200 MW at Zmievska TPP, demonstrated that the heat losses with effluent gases significantly decrease, as well as the heat losses from mechanical incomplete combustion of fuel, which are the main ones in the energy balance of boiler. Air consumption and the fuel carry-over also decrease. The boiler efficiency increases up to 4 %.

A structural scheme of the microprocessor measuring unit, which performs computational procedure (25)–(29) based on the readings of sensors of velocity S_ω and torque S_M, is given in Fig. 6 [12].

The scheme includes the system of automated control of fuel consumption, supplied with the blade dust feeder and the system of feeding activators of combustion to the furnace of a boiler.

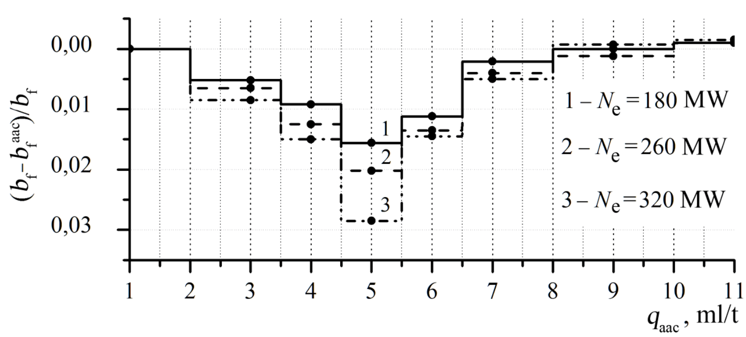
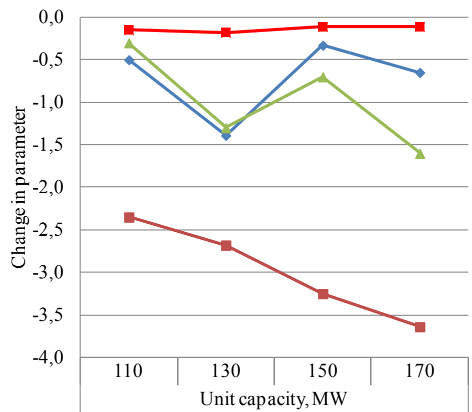


Fig. 4. Dependence of change in specific consumption of fuel on specific consumption of combustion activator in the course of combustion of the A(T) grade coal

The system of precise measurement of the actual current value of coal dust consumption (S_{Bf}) is introduced to the existing ACS together with the regulators of feeding water (P_{Gwf}), fuel (P_{Gf}), and air (P_{Ga}) (the two latter ones ensure standard control of the ratio "fuel-air" and coefficient of air excess (α_{exc}). This substantially increases the effectiveness of existing standard regulator of the ratio "fuel-air". Furthermore, the system of feeding additives-activators with the adjustable precision measuring hopper is used. The measuring hopper is controlled by the regulator of consumption of additives of the combustion activators, which receives the assigning influence by their required amount G^{00}_{aac} and works out this influence, properly regulating the mode of hopper operation. The necessary amount of additives is determined by the actual consumption of coal dust B_f, which is measured by the proposed method and by the norm of additives (n_{aac}) taking into account correction by the fuel quality. Quality coefficient (k_{qual}) can be indirectly determined by the measured value of temperature in the furnace T_{fur} (the higher the fuel quality, under other equal conditions, the higher the temperature in the furnace). Thus, precise regulation of the consumption of additives-activators in accordance with the actual amount of fuel, supplied to the burners, is ensured, and the conditions for its effective combustion are created.



	110	130	150	170
q2	-0,5	-1,39	-0,33	-0,65
q4	-2,35	-2,68	-3,25	-3,64
O2	-0,3	-1,3	-0,7	-1,6
α1	-0,15	-0,18	-0,11	-0,11

Fig. 5. Change in heat losses (q_2, q_4), oxygen content (O_2) and coefficient of excess air (α_1) of the boiler, 200 MW, at the power unit of Zmievska TPP when using the activators of combustion "anaklarid"

Table 1

Effectiveness of using combustion activator

No.	Parameter		Conditional symbols	Measurement units	Electric capacity of unit in mode, N_e, MW						
					130	150	170	110	130	150	170
					Conditions of testing						
					Without anaklarid (basic stage)			With introduction of anaklarid in original air			
	A. Measured values										
1	Temperature of effluent gases		T_{eg}	°C	120	122	128	115	114	120	131
2	Content of burning in carry-over		L_{off}	%	21,7	18,70	22,00	14,54	12,30	10,49	11,24
3	Content of oxygen in balance cross-section		O_2	%	13,3	11,7	12,0	13,0	12,0	11,0	10,4
4	Consumption of natural gas by boiler		B_{gaz}	m^3/h	1830	680,0	1800	0,00	0,00	0,00	0,00
5	Consumption of fresh vapor by turbine		D_v	t/h	440,0	508,9	542,1	402,0	441,7	552,8	586,7
6	Pressure of fresh vapor before turbine		P_v	at.	112,0	102,0	120,0	108,8	108,4	108,0	110,0
7	Temperature of fresh vapor before turbine		T_v	%	545,0	544,6	549,9	542,7	545,4	539,8	535,6
	B. Calculated values										
1	Share of natural gas by heat		β_{gaz}	o.u.	0,05	0,02	0,04	0,00	0,00	0,00	0,00
2	Gross emission of oxides	carbon	B_{COx}	kg/h	68,1	42,0	89,3	89,2	55,6	55,5	64,5
3		nitrogen	B_{NOx}	kg/h	398,0	511,1	587,5	426,0	398,6	583,9	767,3
4	Heat losses	with flue gases, reduced to T_a=30 °C	q_2	%	8,15	6,96	7,54	7,65	6,76	6,63	6,89
5		from mechanic incomplete combustion	q_4	%	6,41	6,93	8,39	4,06	3,73	3,68	4,75
6	Coefficient of air excess	before mode cross section	α_1	o.u.	1,71	1,50	1,42	1,56	1,53	1,39	1,31
7		in balance cross section	α_2	o.u.	2,64	2,19	2,25	2,55	2,26	2,04	1,93
8	Coefficient of boiler efficiency, gross		η	%	83,67	84,43	82,44	86,41	87,73	88,07	86,77

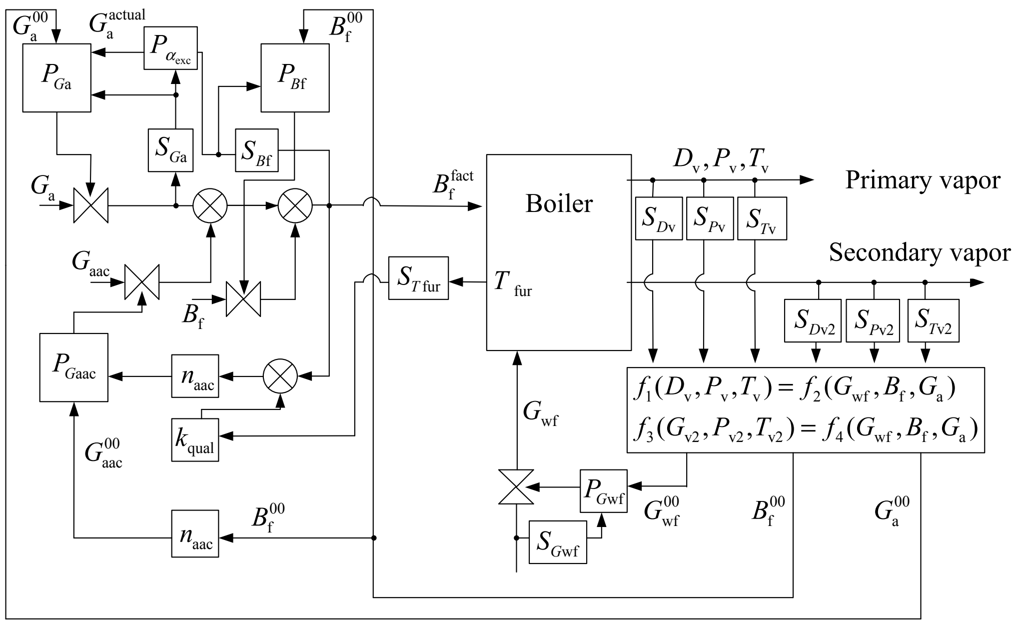


Fig. 6. Functional scheme of energy-saving SAC of the fuel combustion process with the use of additives-activators

6. Discussion of results of the study of increasing the effectiveness of operation of boiler units in the process of combustion of low-quality fuels

An analysis of the existing systems of control and methods for increasing the effectiveness of operation of boilers in the process of combustion of low-quality fuels demonstrated that the use of new technologies can considerably increase the energy effectiveness of boiler operation. Such technologies include the combustion activators that improve the process of combustion of low-quality fuels. An increase in the effectiveness of using combustion activators is possible by means of developing a system of automated feed of the activator to the furnace of a boiler. The developed system of feeding the combustion activator takes into account quality and amount of the supplied fuel, which ensures its effectiveness. Parameter of the combustion activator is included in mathematical models of the system of energy saving control and in the structural schemes of common ACS of a steam boiler. Such integration increases the degree of controllability of the process of feeding the combustion activator and offers the possibility to conduct a comprehensive assessment of effectiveness of using combustion activators for the fuels (coals) of different grades.

This work continues the scientific studies of energy saving control of the power units at the power plants [7, 10–12].

7. Conclusions

Mathematical model of a boiler unit as the object of control was improved. Parameters of the combustion activator that improve the process of combustion of low-quality fuels are included in the model. We proposed a method for increasing the accuracy of measurement and control of feeding solid fuel to the furnace of a boiler, based on the synchronous measurement of rotation frequency of the dust feeder and its shaft torque.

The system of automatic control over the process of feeding the combustion activator to the furnace of a boiler at thermal power stations was developed. The control of feeding the combustion activator is accomplished with regard to amount and quality of the combusted fuel.

Experimental studies demonstrated that the proposed solutions may substantially increase the effectiveness of combustion of low-quality fuel, decrease its specific consumption and increase performance efficiency of power units.

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ANALYTICAL DETERMINATION OF THE ELECTROMECHANICAL SYSTEM STARTING PROCESS EFFICIENCY INDEX WITH REGARD TO THE DISTRIBUTED NATURE OF INPUT PRODUCTS CONSUMPTION

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Робота присвячена аналізу процесів запуску електромеханічних систем, зокрема процесам енергоспоживання і зносу устаткування. Отримано аналітичні вирази для визначення показників процесу запуску з урахуванням розподіленого в часі процесу споживання вхідних ресурсів. Обґрунтовано допустимість застосування спрощеної моделі ресурсоспоживання з зосередженими параметрами для оптимального управління процесом запуску. Отримані результати можуть бути використані при реалізації систем керованого запуску електродвигунів

Ключові слова: керований запуск, розподілене ресурсоспоживання, дрібно-раціональна апроксимація, показник ефективності запуску

Работа посвящена анализу процессов запуска электромеханических систем, в частности процессам энергопотребления и износа оборудования. Получены аналитические выражения для определения показателей процесса запуска с учетом распределенного во времени процесса потребления входных ресурсов. Обоснована допустимость применения упрощенной модели ресурсопотребления с сосредоточенными параметрами для оптимального управления процессом запуска. Полученные результаты могут быть использованы при реализации систем управляемого запуска электродвигателей

Ключевые слова: управляемый запуск, распределенное ресурсопотребление, дробно-рациональная аппроксимация, показатель эффективности запуска

1. Introduction

Starting processes of systems implemented without the use of special engineering solutions have an extreme impact on them. This provision is common, system-wide, and occurs in various fields of engineering. For example, direct-on-line starting of a powerful synchronous motor is equivalent to 500 hours of its normal operation [1]. In order to reduce these losses, special starting systems that allow reducing shock loads to an acceptable level are developed. However, the desired result from the use of starting systems is achieved by increasing the starting process duration, which ultimately reduces the performance of both the starting process and the overall system.

The processes of starting an electromechanical system (EMS) are accompanied by peak power consumption, significant influence on the service life of electromechanical and processing equipment. Starting powerful electric drives, especially in commensurable capacity power supply networks, has a significant impact on a mains supply [2]. Starting voltage