SINGLE-CHANNEL SYSTEM OF AUTOMATIC CONTROL OF THE MODE OF BURNING IN THE BOILER FURNACE

A.S. Karandaev, South Ural State University (Chelyabinsk, Russian Federation)
A.A. Radionov, South Ural State University (Chelyabinsk, Russian Federation)
R.R. Hramshin, Magnitogorsk State Technical University G.I. Nosov (Magnitogorsk, Russian Federation)
V.R. Hramshin, Magnitogorsk State Technical University G.I. Nosov (Magnitogorsk, Russian Federation)
Ju. I. Mamleeva, Magnitogorsk State Technical University G.I. Nosov (Magnitogorsk, Russian Federation)

It is shown that multiple-burner boilers of type «ПТВМ» are the most difficult installations for construction of automatic control systems of a regime of burning (ACS-BURNING). The basic arrangements providing burning of gas in a boiler furnace are observed. Distinctive features are possibility of regulating of a regime of burning quantity and a combination of simultaneously powered burners and absence of possibility of regulating of quantity of air and gas. Thus, as a rule, regulating is carried out manually by change of pressure of gas before burners according to a regime map which is made by an experimentally-settlement way. The estimation of possibilities of automatic control of quality of burning is given. Construction an ACS-BURNING on a regime map with compensation use under the oxygen contents in leaving gases is proved. The ACS-BURNING and principles of feed control of gas are observed the block diagramme developed double-circuit single-channel. It is shown that self-operated control of the contents of oxygen in smoke gases is inexpedient. The system definition of pressure control of gas with an internal loop of regulating of an angle of opening of the valve is given. The expediency of restrictions of pressure control of gas and compensation on oxygen, and also an interdiction for compensation are proved at an obvious deflection from a normal regime. Experimental dependences of a gas rate and multiple-burner boiler efficiency are presented at pressure deflections. The estimation of potential economy of gas is given. Transition from regulating on a regime map to automatic control with use of the electric drive of blow fans is recommended.

Keywords: boiler «ПТВМ», features, fuel burning, a control system, a function chart, a regulation principle, economy of gas.

Creation of the automated control systems by the thermal processes providing improvement of technology, economy of fuel and increase of economic and ecological indicators at thermal energy development, is an actual problem on which decision activity of many specialized institutes and firms is directed [1–3]. Automatic control of a mode of burning has the important practical value for multiple-burner boiler of type «ПТВМ», widespread on domestic thermal power stations and thermal power station. The boiler of type «ПТВМ» in view of design features is the most difficult for ACS-burning realization.

Object of regulation

The basic devices providing burning of gas in a boiler furnace, are schematically shown on fig. 1. From gas-distributing point on the pipeline 1 and to the regulating valve 2 gas under the pressure of P_g arrives in a burner 3. Air under the pressure created blow fan 4, on an air line 5 and to the regulating valve 6 (the directing device) moves in a burner under the pressure of P_a. The quality of a mix defined by a parity air-gas, defines burning indicators, including efficiency of use of gas. The burner in a boiler furnace 7 is heated up by the heat-carrier (water) proceeding in pipes 8, and burning products - smoke gases, are taken away in atmosphere through a chimney 9. The flue device differs depending on type and design features of boiler, but generally in it is available smoke sucker 10 with the electric motor 11 and regulating gate 12 [4].

On fig. 2 the cut of a boiler furnace (top view) is conditionally shown. The water which is pumped over on pipes 1, forms together with external fettling boiler walls. Burners functionally share on kindling 3, supplied the control of presence of a burner and protection against it extinction, and remote 4, activated as required for regulation heat productivity a boiler. In the presence of a burner kindling Burners any remote burner (group of Burners), being close, at its switching-on lights up from a burner kindling. A condition fail-safety is work of all of four kindling Burners.

In a boiler furnace the general burner, therefore power and ecological indicators of quality of burning of gas besides a parity air-gas is formed depend on other factors, basic of which the quantity and a combination of the turn on burners and air temperature are. One more factor are features of a design of a boiler:

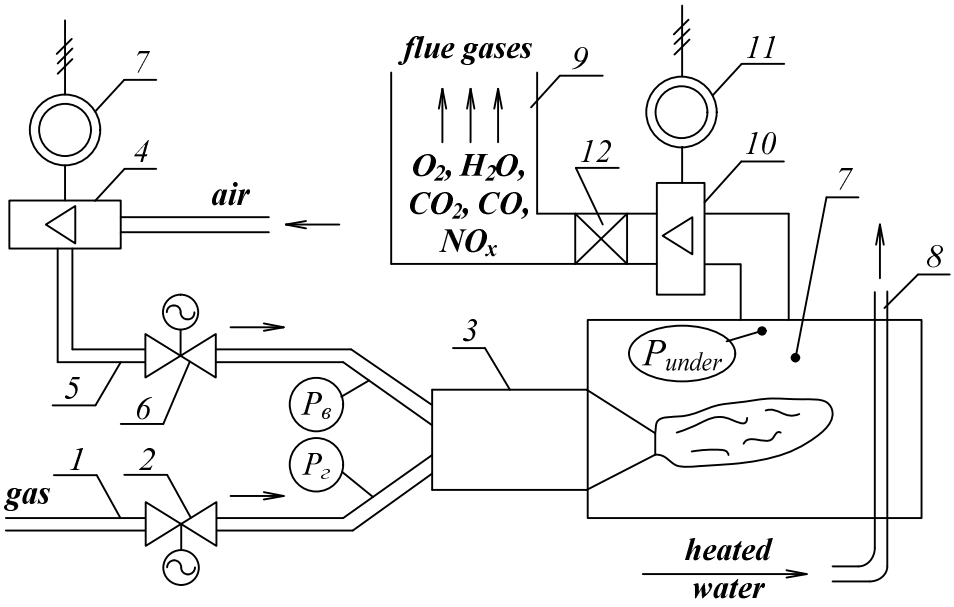

Fig. 1. The devices providing burning of gas in a boiler furnace

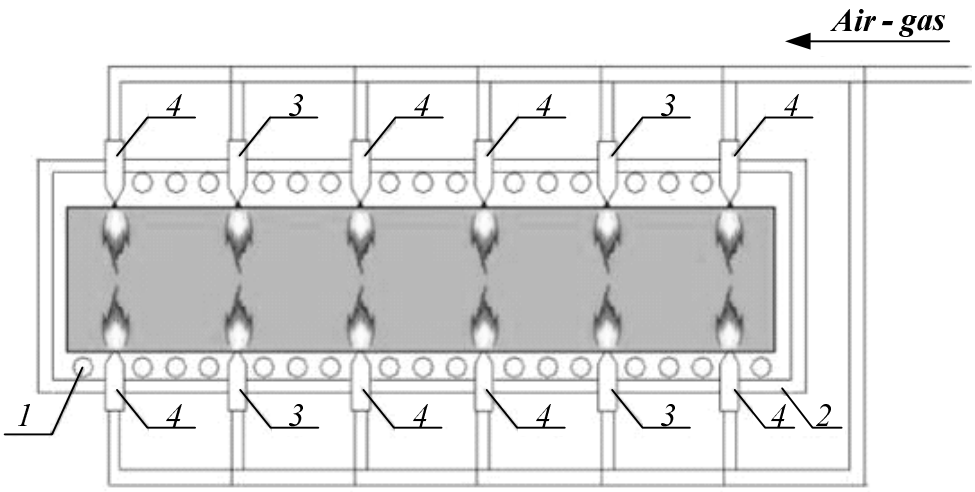

Fig. 2. A conditional cut of a boiler furnace

blow fans take away air from the general for them an air line, therefore at switching-on - switching-off even one burner the quantity of submitted air in working Burners changes on volume as pressure in this air line depends on the expense of air and changes. Same concerns and the gas expense through burners as they are supplied with gas from one highway through regulating valve of pressure of gas. Blow air is not warmed up and has the temperature close to temperature of external air, and in equal volumes of air because of change of its density at various temperatures the quantity of oxygen different in absolute value contains.

Possibilities of regulation of quality of burning are limited by a boiler design: it is impossible to regulate quantity of air and gas in each burner individually, and the quantity of submitted air is not regulated in general. There is actually only one possibility – regulation of pressure of gas before all burners simultaneously. Now in most cases this regulation is conducted manually by change of pressure of gas before burners according to a regime card.

The regime card is the regulating document for regulation of quality of burning and is made by an experimentally-settlement way, and the structure of departing gases (single measurement) for various modes is defining. It represents the table 1, as required value in which pressure of gas before a boiler (the gas expense through burners), and independent parameters – a combination of the turn on burners and temperature blow air serves. The fragment of a regime card is resulted in the table.

Advantages of an experimentally-settlement regime card - in its simplicity, therefore until recently on the majority thermal station it is the document, which operation personnel should observe strictly. Increased requirements to profitability of use of fuel, ecological

Table 1

Fragment of a regime card of boiler «ПТВМ»

Air-blast temp., °C	Quantity of the turn on Burners									
	4			6			----	16		
	P_g, kgf/sm^2	Q_g, m^3/h	*CPA*, %	P_g, kgf/sm^2	Q_g, m^3/h	*CPA*, %		P_g, kgf/sm^2	Q_g, m^3/h	*CPA*, %
+5	0,228	3903	93,3	0,188	5510	93,4	----	0,165	12338	92,0
0	0,236	3970	93,1	0,195	5610	93,1	----	0,171	12564	91,7
-5	0,245	4049	92,9	0,202	5715	92,9	----	0.178	12798	91,5
----	----	----	----	----	----	----	----	----	----	----
–20	0,275	4289	92,2	0,227	6054	92,2	----	0,199	13557	90,9

indicators, the control over observance of specifications compel operation service to correct regime cards much more often, than in previous years: once in 6 months, at former term of their action - once in 3 years. Now continuous monitoring of structure of departing gases is even more often carried out that also shows increased requirements to quality of a regime card. Thereupon at this conjuncture operation boiler unit on the domestic thermal objects which have been not equipped with adjustable electric drives forced-draft of mechanisms, ***perfection and introduction of the ACS-BURNING, the regime cards constructed on the basis of traditionally used personnel are expedient***.

Automatic control system of a mode of burning

Now find application various on construction of automatic control system of a mode of burning. The most obvious way is based on the logician of a hand control and following principles [5]:

1. Orientation to a regime card of a boiler is necessary for observance of a demanded parity air-gas as regarding a temperature parity blow air and pressure of gas before a boiler, and concerning an order of switching-on - switching-off of pairs burners (symmetry of a burner).

2. In view of dependence of quality of burning on set of collateral factors - humidity of air and other weather conditions, and also imperfection of a regime card, correction of a mode of burning under the oxygen content in leaving gases is necessary.

3. The most authentic results of gauging of the content of oxygen in leaving gases at change of thermal capacity of a boiler (quantity of the turn on burners) are provided at an arrangement of the gauge of oxygen in the geometrical centre of a boiler over top convections (horizontal pipes with heat-carriers, meant for selection of heat of smoke gases).

Thus, the ***regime card can be put in a basis of algorithm of ACS-burning, and mode correction should be conducted under the oxygen content*** as this indicator precisely enough reflects both power (boiler EFFICIENCY), and ecological characteristics of a mode (emissions in atmosphere of carbonic oxide and nitrogen oxides). Orientation to a regime card is necessary also because burning mode not always expediently to regulate on the oxygen content. For example, at firing a boiler after long stop during time before warming up the oxygen content can essentially differ from set, therefore it is necessary to do without correction on oxygen.

The block diagramme developed ACS-burning with the uncontrollable channel of giving blow air and operating influence only on regulating valve of giving of gas is shown on fig. 3. Such variant of single-channel local system meets requirements of regulation of boiler «ПТВМ» with uncontrolled electric drives blow fans and gates on air lines. The executive mechanism is the regulating valve of pressure of gas with the asynchronous electric drive 1 and thyristor the actuator 2, and object of management – a burning burner in a boiler furnace 3. Thermal capacity of a boiler changes manually by switching-on – switching-off burners from operator station.

Though content O_2 in smoke gases objectively enough reflects burning process, direct regulation of this indicator is inexpedient. It speaks complexity of transfer function of object $W_{ob}\ (p)$ and ambiguity of necessary reaction of a control system on revolting influences. For example, at addition of burners a burner in a fire chamber and structure of smoke gases temporarily sharply vary, but after the termination of transient burning indicators are restored without intervention of the operator or a control system. Therefore value O_2 is used for correction of the task for value of pressure of gas $P_{g.r.}$, and an external contour of regulation is the contour of pressure of gas with a regulator 4. The value of task $P_{g.r.}$ is formed programmatically on a regime card (like table 1) taking into account quantity of the turn on burners and linearization dependences of pressure on temperature $T°_{b.a.}$ blow air (for reduction of step-type behaviour of regulation). Signal $P_{g.r.}$ is compared to current value of pressure of gas P_g and summarized with the signal of correction $P_{g.c}$ formed by a contour of correction on oxygen with a regulator 5.

Target value of a regulator 4 is the task signal α_{task} on a corner of opening of the regulating valve 1. Transfer function $W_1\ (p)$ a regulator depending on requirements to value of a static error can correspond as aperiodic, and integrating to links. In case of an integrating link from stability conditions the internal contour of regulation of a corner α as transfer function $W_\alpha\ (p)$ the valve 1 represents integrated dependence of

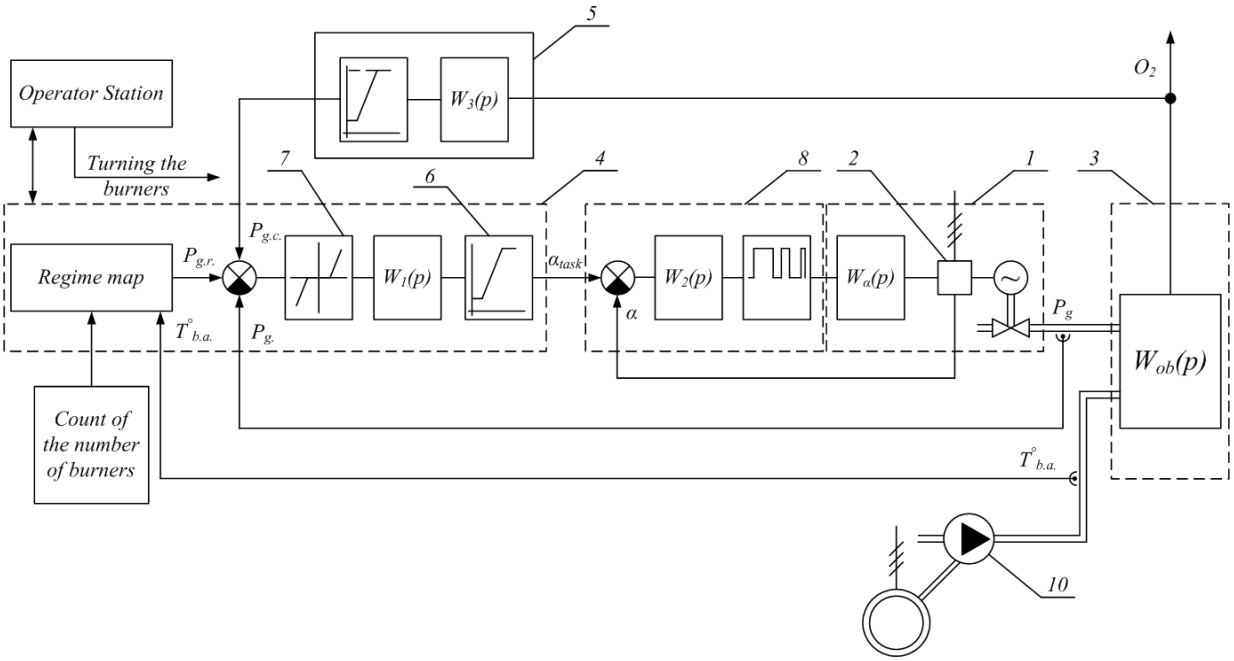

Fig. 3. The ACS-burning block diagram at uncontrolled giving blow air

pressure on frequency of rotation of the electric motor is necessary.

On an exit of a regulator 4 presence of a link 6 for restriction of maximum and minimum values P_g is necessary as the exit of pressure of gas for admissible borders causes protection operation. Also formation of a zone of tolerance, a link 7, for an exception of frequent (oscillatory) changes of a corner of opening of the valve is necessary. The regulator of a corner of opening 8 with transfer function W_2(p) represents the pulse-width modulator of a mismatch of signals α_{task} and α with changing on an exit in width and intervals between impulses. Accuracy of regulation P_g depends on the minimum width of the impulse which really achievable value makes 0,1 sec. The operative range of a contour of correction on oxygen with a regulator 5 should be limited, as the measured structure of gases not always is defined by a parity "air-gas". At an exit of the content of oxygen for the established borders, for example, 1,6-2,1 %, the regulation system should inform the operator.

At change of an operating mode of a boiler the oxygen content in departing gases in a point of its measurement varies with a delay estimated on minutes that is caused by transport delay rising upwards (to top convection) gases. Besides, there is some persistence the measurement channel (an order 15). However this delay in correction on oxygen for conditions of long continuous process has no essential value. Transient time at such revolting influence as burner switching-on, makes 4–5 minute.

Operating experience ACS has revealed expediency ***of restrictions on regulation of pressure of gas and correction on oxygen***.

First, boundary conditions on pressure of the gas, following of a regime card and settings hardware protection are known. Therefore program restrictions on minimum (0,1 kG/sm^2) and maximum (0,3 kG/sm^2) to values of pressure are carried out.

In the second, pressure with gas-distributing point («ГРП»), adjustable membrane regulator (type «РДУК») at level 0,4 kG/sm^2, can have a variable component of changing frequency that causes difficulties in a filtration of signals of gauges. Therefore for prevention of these insignificant from the point of view of technology of fluctuations (the amplitude no more than 0,0008 kG/sm^2), is entered a tolerance zone in regulation of pressure of gas in width ± 0,001 kG/sm^2 .

In the modes characterized by a sharp deviation of the content of oxygen in smoke gases from set, it is recommended to limit influence of a correcting contour and to forbid an essential deviation from a regime card. Following restrictions are necessary:

1. The value of the resolved deviation of pressure of gas from values of a regime card for correction on oxygen at level ±15 % is limited. At an authentic regime card of such range it is quite enough and necessity of drawing up of a new regime card otherwise is obvious.

2. The tolerance zone in regulation of oxygen in width ±0,2 % on absolute value is set. Such accuracy of regulation lies within an error of measurement of oxygen and is sufficient for content of an optimum mode of burning.

3. The interdiction for correction is entered at an obvious deviation from a normal mode. For example, a crack in lining a boiler or the open repair hatch conduct to increase in the content of oxygen to 5 %, and to compensate this emergency increase in the expense of gas it is inexpedient. Therefore correction with en-

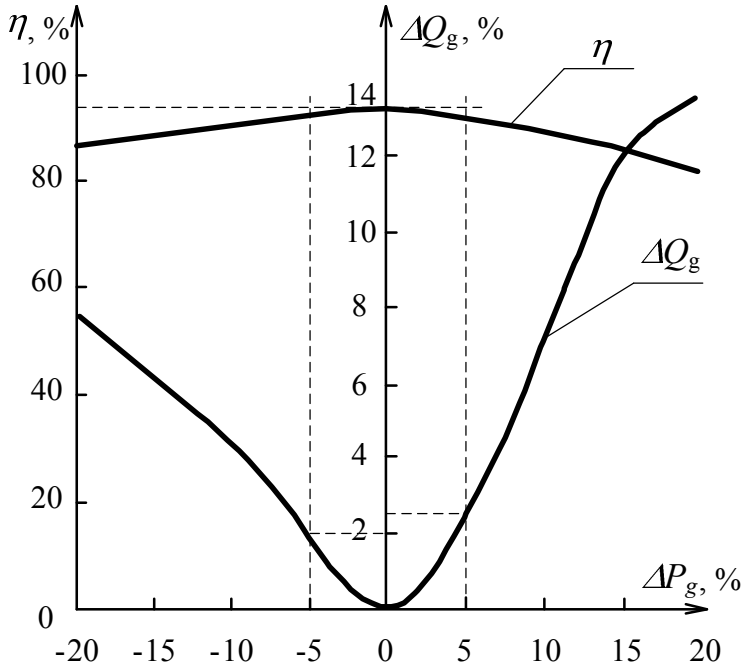

Fig. 4. Experimental indicators of use of gas

durance of time and the notification of the operator is automatically disconnected, and regulation is conducted only on a regime card. After elimination of the reason of switching-off correction again automatically switch on.

The operating procedure of the described system consists in the following. After firing switch on ACS, and pressure of gas is established according to a regime card. The switching-on - switching-off of remote burners which is carried out by the operator for the purpose of regulation of thermal capacity, causes respective alteration of pressure of gas before a boiler at the expense of pulse-width management of the valve. Regulation time at such revolting influence makes 7–10 s. At the greatest possible pressure of gas 0,4 kG/sm^2 regulation is conducted with accuracy 0,001 kG/sm^2.

Temperature change blow air is fulfilled with step-type behavior 0,1°C (on a regime card 5 °C) and also leads to the new established values of pressure of gas. The deviation of the content of oxygen in smoke gases from a preset value makes ±0,3 %.

Economy of gas

Possibilities of economy of gas consist in accuracy of regulation of a mode of burning and an exception of an exit of a mode of an optimum zone. Deviations from an optimum mode conduct to the gas overexpenditure on unit of developed thermal energy.

Experimental dependences of the overexpenditure of gas ΔQ_g and efficiency η multiple-burner boiler «ПТВМ-100» are presented on fig. 4. Results are received by a deliberate deviation of pressure of gas ΔP_g from the value corresponding to qualitative burning of gas, a point 0 on an axis of abscissas. Quantity of developed thermal energy and CPA. A boiler η paid off under characteristics of the heat-carrier and the gas expense.

As appears from drawing, both at positive, and at negative deviations ΔP_g there is a gas overexpenditure $\Delta Q_г$ for development of the same quantity of heat. If to assume a deviation in ±5 % that is quite real at the described way of regulation the gas expense in a positive zone increases by 2,6 %. It is accompanied by the big emission in carbonic oxide atmosphere, and in negative – on 2 % with the raised emissions of oxides of nitrogen [6]. Thus in both cases approximately for the same values decreases EFFICIENCY η.

Transition is necessary for reduction of unjustified losses of gas from the considered management of burning on regime cards to automatic with use of the adjustable electric drive blow fans and smoke suckers, and also the direct and continuous control of structure of smoke gases. It creates possibility of complex management of target indicators heat station and constructions of system of automatic control by process of development of thermal energy [7, 8].

This work is supported by the Ministry of Education and Science (contract № 14.B37.21.0334).

References

1. Medvedev V.N., Karandaev A.S., Karandaeva O.I., Mamleeva Ju.I., Hramshina E.A. Technological Demand and Assessment of Efficiency for the Introduction of Frequency and Adjustable Electric Drives on Objects of The Thermal Power Plant, *Vestnik IGJeU* [*Vestnik ISPU*], 2012, no. 6, pp. 100–104.

2. Hramshin V.R., Karandaeva O.I., Mamleeva Ju.I., Petuhova O.I., Hramshina E.A. Electric Drive as a Means of Saving in the Hydraulic Systems of Pumping Units [Reguliruemyj elektroprivod kak sredstvo jenergosberezhenija v gidravlicheskih sistemah nasosnyh agregatov]. *Mezhvuzovskij sbornik nauchnyh trudov «Elektrotehnicheskie sistemy i kompleksy»* [*Interuniversity Collection of Scientific Papers "Electrical Systems and Complexes"]*, Magnitogorsk, MGTU, 2012, vol. 20, pp. 354 – 360.

3. Krylov Ju.A., Medvedev V.N., Karandaev A.S. Experimental Study of Self-Frequency-Regulated Electric Drives with Violations of Electric Power Supply [Eksperimentalnye issledovanija samozapuska chastotno-reguliruemyh elektroprivodov pri narushenijah elektrosnabzhenija]. *Trudy VII mezhdunarodnoj (XVIII vserossijskoj) nauchno-tehnicheskoj tonferencii po avtomatizirovannomu jelektroprivodu [Proceedings of the VII International (XVIII All-Russian) Scientific and Technical Conference on Automated Electric]*, Ivanovo, ISPU, 2012, pp. 161–165.

4. Krylov Ju. A., Medvedev V.N., Karandaev A.S., Kornilov G.P. *Energosberezhenie v teplojenergeticheskom hozjajstve goroda sredstvami reguliruemogo Elektroprivoda. [Energy Saving in the Economy of Thermal Power Facilities Regulated Electric]*. Magnitogorsk, MGTU, 2012, 202 p.

5. Vajner I.G., Krylov Ju.A., Panshin A.S. Regulation of Thermal Capacity Boiler Unit Type «ПТВМ» [Regulirovanie teplovoj moshhnosti kotloagregatov tipa PTVM], *Promyshlennaja energetika* [*Energy Industry*], 2001, no.4, pp. 18–22.

6. Belikov S.E., Kotler V.R. Comparison Ecological Characteristics of Industrially-heating Boiler with Injection and Pressure Head Burners [Sravnitelnye ekologicheskie harakteristiki promyshlennootopitelnyh kotlov s inzhekcionnymi i napornymi gorelkami], *Promyshlennaja energetika* [*Energy Industry*], 1999, no. 5, pp. 44–47.

7. Krylov Ju.A., Karandaev A.S., Hramshin R.R., Gubajdullin A.R., Hramshin V.R. Principles of Construction System of Automatic Control in the Process of Development of Thermal Energy on the Basis Adjustable Electric Drive [Principy postroenija sistemy avtomaticheskogo upravlenija processom vyrabotki teplovoj jenergii na osnove reguliruemyh jelektroprivodov]. *Trudy chetyrnadcatoj nauchno-tehnicheskoj konferencii «Elektroprivody peremennogo toka». [Alternating Current Electric Drives: Works of the Fourteenth Scientific and Technical Conference]*, Ekaterinburg, «Ural Federal University named after the first President of Russia B.N. Yeltsin», 2012, pp. 211–214.

8. Krylov Ju.A. Thermal Station as Object of Automatic Control [Teplovaja stancija kak obekt avtomaticheskogo regulirovanija], *Promyshlennaja energetika* [*Energy Industry*], 2008, no. 3, pp. 45–49.

УДК 314.212:620.111.3

ОДНОКАНАЛЬНАЯ СИСТЕМА АВТОМАТИЧЕСКОГО РЕГУЛИРОВАНИЯ РЕЖИМА ГОРЕНИЯ В ТОПКЕ КОТЛА

А.С. Карандаев, А.А. Радионов, Р.Р. Храмшин, В.Р. Храмшин, Ю.И. Мамлеева

Показано, что многогорелочные котлы типа ПТВМ являются наиболее сложными объектами для построения систем автоматического регулирования режима горения (АСР-горения). Рассмотрены основные устройства, обеспечивающие горение газа в топке котла. Отличительными особенностями являются возможность регулирования режима горения количеством и комбинацией одновременно включенных горелок и отсутствие возможности регулирования количества воздуха и газа. При этом, как правило, регулирование осуществляется вручную путем изменения давления газа перед горелками согласно режимной карте, которая составляется экспериментально-расчетным путем. Дана оценка возможностей автоматического регулирования качества горения. Обосновано построение АСР-горения по режимной карте с использованием коррекции по содержанию кислорода в уходящих газах. Рассмотрены структурная схема разработанной двухконтурной одноканальной системы АСР-горения и принципы регулирования подачи газа. Показано, что прямое регулирование содержания кислорода в дымовых газах нецелесообразно. Дано описание системы регулирования давления газа с внутренним контуром регулирования угла открытия клапана. Обоснованы целесообразность ограничений регулирования давления газа и коррекции по кислороду, а также запрет на коррекцию при явном отклонении от нормального режима. Представлены экспериментальные зависимости расхода газа и коэффициента полезного действия многогорелочного котла при отклонениях давления. Дана оценка потенциальной экономии газа. Рекомендован переход от регулирования по режимной карте к автоматическому регулированию с использованием электропривода дутьевых вентиляторов.

Ключевые слова: котел «ПТВМ», особенности, сжигание топлива, система управления, функциональная схема, принцип регулирования, экономия газа

Литература

1. Технологическая востребованность и оценка эффективности внедрения частотно-регулируемых электроприводов на объектах тепловой электростанции / В.Н. Медведев, А.С. Карандаев, О.И. Карандаева, и др. // Вестник ИГЭУ. – 2012. – № 6. – С. 100–104.

2. Регулируемый электропривод как средство энергосбережения в гидравлических системах насосных агрегатов / В.Р. Храмшин, О.И. Карандаева, Ю.И. Мамлеева и др. // Электротехнические системы и комплексы: межвуз. сб. науч. тр. – Магнитогорск: МГТУ, 2012. – Вып. 20. – С. 354–360.

3. Крылов, Ю.А. Экспериментальные исследования самозапуска частотно-регулируемых электроприводов при нарушениях электроснабжения / Ю.А. Крылов, В.Н. Медведев, А.С. Карандаев // Труды VII Международной (XVIII Всероссийской) научно-технической конференции по автоматизированному электроприводу: ИГЭУ. – Иваново, 2012. – С. 161–165.

4. Энергосбережение в теплоэнергетическом хозяйстве города средствами регулируемого электропривода: моногр. / Ю.А. Крылов, В.Н. Медведев, А.С. Карандаев, Г.П. Корнилов. – Магнитогорск: Изд-во Магнитогорск. гос. техн. ун-та им. Г.И. Носова, 2012. – 202 с.

5. Вайнер, И.Г. Регулирование тепловой мощности котлоагрегатов типа ПТВМ / И.Г. Вайнер, Ю.А. Крылов, А.С. Паньшин // Промышленная энергетика. – 2001. – № 4. – С. 18–22.

6. Беликов, С.Е. Сравнительные экологические характеристики промышленно-отопительных котлов с инжекционными и напорными горелками / С.Е. Беликов, В.Р. Котлер // Промышленная энергетика. – 1999. – № 5. – С. 44–47.

7. Принципы построения системы автоматического управления процессом выработки тепловой энергии на основе регулируемых электроприводов / Ю.А. Крылов, А.С. Карандаев, Р.Р. Храмшин и др. // Электроприводы переменного тока: труды четырнадцатой научно-технической конференции. – Екатеринбург: УрФУ. – 2012. – С. 211–214.

8. Крылов, Ю.А. Тепловая станция как объект автоматического регулирования / Ю.А. Крылов // Промышленная энергетика. – 2008. – № 3. – С. 45–49.

Карандаев Александр Сергеевич, доктор технических наук, профессор, главный научный сотрудник кафедры теоретических основ электротехники, Южно-Уральский государственный университет (г. Челябинск, Российская Федерация), askaran@mail.ru

Радионов Андрей Александрович, доктор технических наук, профессор, декан энергетического факультета, заведующий кафедрой теоретических основ электротехники, Южно-Уральский государственный университет (г. Челябинск, Российская Федерация), radionovaa@susu.ac.ru

Храмшин Рифхат Рамазанович, кандидат технических наук, доцент кафедры электротехники и электротехнических систем, Магнитогорский государственный технический университет им. Г.И. Носова (г. Магнитогорск, Российская Федерация), hramshinrr@mail.ru

Храмшин Вадим Рифхатович, кандидат технических наук, доцент кафедры электротехники и электротехнических систем, Магнитогорский государственный технический университет им. Г.И. Носова (г. Магнитогорск, Российская Федерация), hvr_mgn@mail.ru

Мамлеева Юлия Игоревна, аспирант кафедры электротехники и электротехнических систем, Магнитогорский государственный технический университет им. Г.И. Носова (г. Магнитогорск, Российская Федерация).

Поступила в редакцию 14.03.2013 г.