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DEVELOPMENT OF AN IMPROVED DEVICE TO CONTROL FLAME BRIGHTNESS IN COMBUSTION CHAMBERS OF STEAM BOILERS

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Наведені методи контролю якості вугілля. Для підпалювання вугільного факела необхідні розпалювальні мазутні або газові форсунки. Ці форсунки можуть також включатись при погасанні основних пальників. Необхідний індивідуальний контроль за роботою кожного пальника у всьому діапазоні навантажень і режимів агрегату. Завданням розробки є удосконалення пристрою контролю для подальшого автоматичного керування процесом спалювання вугілля

Ключові слова: факел, пальник, оптичний контроль, продукти горіння, пиловугільне паливо, спектр, топка

Приведены методы контроля качества угля. Для поджигания угольного факела необходимы растопочные мазутные или газовые форсунки. Эти форсунки могут также включаться при погасании основных горелок. Необходим индивидуальный контроль за работой каждой горелки во всем диапазоне нагрузок и режимов агрегата. Задачей разработки является усовершенствование системы контроля для дальнейшего автоматического управления процессом сжигания угля

Ключевые слова: факел, горелка, оптический контроль, продукты горения, пылеугольное топливо, спектр, топка

1. Introduction

In the Ukrainian energy sector, about 200 billion kWh of electricity is produced annually. At the same time, almost half of this energy is generated by thermal power plants and power stations.

In recent years, the heat from coal combustion has decreased significantly, its ash content has increased 2.5 times, and the sulfur content has increased substantially, too. All this reduces the possibility of using pulverized coal only and requires using additional fuels such as natural gas and black residual oil. Despite the fact that coal burning is much more profitable than burning natural gas, it is necessary to increase the quality of coal by reducing its ash content. To increase the combustion efficiency of coal, a suspension is produced from it and burnt in a high-temperature pulverized coal flame. The disadvantage of the process is the significant cost of coal enrichment and transportation.

In order to improve fuel quality, in 2012 the new State Standard DSTU 4083-2012 "Coal and Anthracite for Pulverized Burning at Thermal Power Plants" was adopted [1].

For automatic control of the coal composition, the flow is based on the methods of absorbing or dispersing electromagnetic radiation, ultrasound, charged particles, the natural radioactivity level of the accompanying rocks and neutron activation or powerful laser activation.

It is important to develop a device to control fire brightness as it provides the possibility of safe and economical control of the operating mode of the boiler furnace.

The firm that has been developing flame control sensors for more than 20 years emphasizes that the existing sensors [2]:

– have insufficient reliability of controlling the presence and absence of flames;

– have low selectivity in determining a fading burner;

– are sensitive to external illumination;

– cost much.

The flame indicator must have high reliability and selectivity for igniting or extinguishing the torch, as well as the absence of reaction to any other sources of fire. The great difficulty is the uneven burning of the flame along the torch. The dust burner is heated by means of a black fuel nozzle. The operation of the burner control should be carried out in accordance with the operation of the dust system: the entire group of burners, which is powered by one dust system, must be switched on or off simultaneously with the system. It is necessary for the signal value of the sensor to exceed the noise level significantly.

2. Literature review and problem statement

In recent years, optical pyrometers have been widely used, and their principle is based on registering a continuous spectrum of radiation with its maximum in the infrared region. In [3], to control temperature, an uncoated quartz light fiber is used in the combustion zone. Heated to the flame temperature, the input end of the optical information channel becomes a secondary source of radiation. In this case, the temperature range in the control zone is 1400–1863 degrees Celsius, and the wavelength of the radiation is (3.0–4.5) µm. The disadvantage of this sensor is that the melting point of quartz is 1710 degrees, which leads to a fast failure of the sensor.

The analysis of the current level of combustion gauges shows that besides the spectral methods for controlling the temperature of flames and gases, an additional ionization or photocell is used to convert the electrical conductivity pulsation or brightness of the burner torch into an electrical signal that characterizes the radiation of the torch in the burner [4]. The degree of ionization and electrical conductivity of the gases of pulverized burners is influenced by the size of the burning particles and the content of impurities in the fuel. The disadvantage of an ionization sensor is the rapid failure of its electrodes. In this case, the factors that matter are the material from which the electrode is made, its shape, and its surface condition. The natural frequency of the flame flushing fluctuates around the average frequency of 3–4 Hz. Fixation of the variable component of radiation allows reducing the effect of the constant heat field of the furnace walls on the accuracy of measurements [4]. To select the radiation spectrum of combustion products, optical filters are used, which are subdivided into strips that pass a narrow band of wavelengths of radiation, longwave and shortwave, and cut off the waves whose length is larger or smaller than the selected range. Light filters are chosen in such a way that they not only allocate the desired spectrum of radiation but also weaken the radiation of other combustion products [5]. A more detailed choice of optical interference filters is possible only after determining the radiation spectrum of the main combustion products. For the lens, it is better to choose conventional optical glass that has sufficient transparency in the visible and near-infrared spectrum, is well processed and has rather high physical and mechanical properties [5].

The method of selective control of the burner flame uses the ratio of the emission spectra of combustion products among themselves or in relation to the intensity of the radiation of the torch edges.

The installation of temperature sensors directly near the source of radiation is impossible, since their operating temperature does not exceed 125 °C. The large distance between the sensor and the radiation source filled with gases and combustion products becomes an additional source of measurement errors [4]. Therefore, the German company AMX ENGINEERING has equipped its sensors with heat-resistant light lines [6], which has brought the sensor's inlet to the source of radiation and has significantly increased the accuracy of measurements. However, the angle of view of these sensors is 6 degrees, which significantly reduces the control area of the torch [6]. The choice of light conductors, light filters and light detectors themselves depends on the emission spectrum of the combustion products. From the experience of leading companies, it is known that the control of combustion of gas and black fuel oil is mainly based on the ultraviolet spectrum of radiation; for coal, these factors are infrared radiation and part of the visible spectrum [6]. In [7, 8], optical sapphire fibers are used for light fibers, but the transparency region does not cover most of the spectrum.

The disadvantage of known devices is the low accuracy of control due to the lack of compensation for optical interference occurring in the space between the device and the object of control.

The basic scheme of a two-channel infrared temperature sensor is given in [9]. Its design, however, is not adapted for use in production conditions. It is known that the DURAG flame sensors of AMH ENGINEERING LLC have two logarithmic amplifiers [6]. This is due to the fact that in the circuit of the electronic unit to calculate the ratio of signals from two parts of the spectrum, it is necessary to obtain the difference between the logarithms of these two signals [10]. The disadvantage of this device is the lack of an automatic measurement correction input, taking into account the completeness of the combustion of coal fuels.

3. The aim and objectives of the study

The aim of the study is to determine the spectral and temperature characteristics of the products formed during the combustion of pulverized coal, which will increase the selectivity of the device to control the brightness of the flame.

To achieve this aim, the following objectives are set to be done:

– to determine the emission spectrum of combustion products and temperature distribution along the torch;

– to develop a functional scheme of the device for controlling the brightness of the flame;

– to substantiate the principle of the device operation;

– to develop an electronic scheme of the flame brightness control device.

4. Research and development of the device to control fire brightness in the furnaces of steam boilers

4. 1. Determination of the emission spectrum of combustion products and the temperature distribution along the torch

Depending on the intensity, the flame of the torch is divided into three temperature zones: initial, medium, and final. In [10], there is a band of the maximum radiation of combustion products in the infrared region of the spectrum: H_2O – 2.7 μm, CO_2 – 4.3 μm, CO – 4.7 μm, nitrogen oxides in the amounts of 4.48 μm, 2.87 μm, and 5.25 μm; sulfur oxides in the amounts of 7.28 μm and 3.98 μm; and CH_4 – 3.32 μm. In addition, solid carbon particles (soot) have a continuous spectrum of radiation with a maximum of 0.9 μm, which depends on the temperature and size of the particles.

It is very interesting to explore the possibility of simultaneous control of CO and CO_2 in relation to background bright temperatures [11]. However, the method is more suitable for use in the metallurgical industry.

In the initial part of the torch, fluctuations occur at a frequency of 800 to 1500 Hz, and in the tail, the frequency is less than 200 Hz. Spectra of individual components can be selected from the general spectrum of combustion products by using optical light interference filters and reducing the diaphragm opening [4]. With these filters, it is possible to select a band ranging from 1.0 to 10 nm.

4. 2. The functional scheme of the device to control fire brightness

The functional scheme of the flame brightness control device is shown in Fig. 1.

The device contains sequentially connected optical elements located in a diaphragm tube. The outputs of light detectors through electronic amplifiers and frequency spectrum analyzers are connected to the corresponding inputs of a logic block. The output of the logic block is connected to the output block (20). In this case, the electronic amplifiers, frequency spectrum analyzers, logic block and output block are located in a remote electronic unit.

4. 3. The principle of the flame brightness control device

The diaphragm tube (1) protects the optical system from extraneous light and pollution. The lens (2) generates a torch image in the input plane of the optic fiber distributor (3) that divides it into three channels. The condensers (4, 5, and 6) are intended for radiation concentration at the light detectors (10, 11, and 12). With the help of the interference filters (7, 8, and 9), the spectral distribution of the torch radiation is performed according to the corresponding optical channels. The light detectors (10, 11, and 12) convert the radiation energy of the torch into an electrical signal amplified by the electronic amplifiers (13, 14, and 15). The spectrum analyzers of the frequencies (16, 17, and 18) filter the pulsation frequencies characteristic of the individual parts of the torch flame. The logic block (19) is designed to generate monitoring and control signals as well as to transmit these signals through the output unit (20) to the control system.

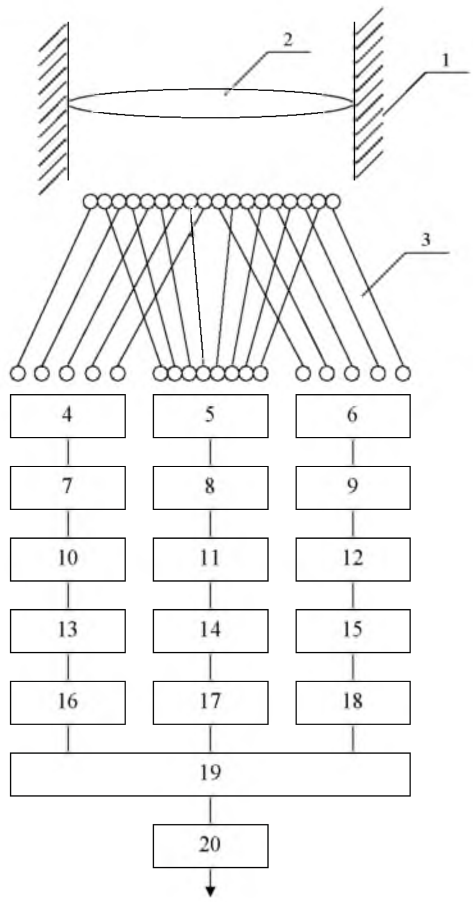


Fig. 1. The functional scheme of the device to control fire brightness: 1 – a tube; 2 – a lens; 3 – an optical distributor, made in the form of an optical fiber transformer; 4, 5, and 6 – condensers; 7, 8, and 9 – interference filters; 10, 11, and 12 – light detectors; 13, 14, and 15 – electronic amplifiers; 16, 17, and 18 – spectrum analyzers; 19 – a logic block; 20 – an output block

In the zone of the torch, products with a band of maximum radiation in the infrared spectrum range from 2.82 to 5.27 μm are formed. When performing selective control, it is possible to use the above lines for one of the products of combustion with the use of light detectors 10 and 12. For the light detectors, the optical fiber divider splits the area of the torch image in two. The ratio of the output signals of these two channels helps make conclusions about the brightness of the flame. To control the concentration of solid particles (soot, ash), which are formed in the space between the device and the object of control, an additional channel has been introduced. In the channel to light detector 11, through the optic fiber distributor (3) and through condenser 5 and interference filter 8, there appears a full image of the torch flame. In this case, interference filter 8 and light detector 11 are estimated for a wavelength equal to 0.9 μm.

The spectral absorption coefficient for such a medium can be determined analytically. When the optical size of the particles is changed from 5 to 30 μm, the spectral absorption coefficient recursively changes in this range. With an unlimited increase in the size of the particles and a reduction in the wavelength of the incident radiation, the particles in their optical properties are similar to large opaque screens. The effect of the concentration of solids on the degree of reducing the transparency of the medium is taken into account by the logic block (19) in diagnosing the actual flame brightness and applying a control signal to the output block (20). If the signal ratio decreases to 10 %, the output unit (20) indicates the flame fading.

For more precise control of the combustion mode, an additional selection of signals is used with spectrum analyzers of the flux pulsation (16, 17, and 18).

The introduction of an additional channel to control the value of interference can help make an adjustment for the effect of changing the optical properties of combustion products on the results of measurements, which increases the accuracy of control.

The performance of the proposed device depends on the correct optical material. The optimal spectral signal ratio begins to be provided with the choice of filters. The greatest accuracy can be obtained with the help of interference filters that transmit wide bundles of light up to 10–20 degree angles. The maximum filter passage corresponds to the wavelengths for which the thickness of the dielectric layer is multiplied by half the wavelength.

The disadvantage of the existing system is the large gap between the PECs (photoelectronic converters) and their location near the torch burner. These shortcomings can be prevented by means of a special optic fiber transformer that provides high transmittance and decomposes the image into elements, which makes it possible to implement any encryption law and enlarge the image. The value of the transmission coefficient of the optical fiber wiring binder is directly proportional to the total useful area of the ends of the fibers [5]:

$$\eta=\frac{S_1}{S_0}\tau(1-\rho^2)\sin U, \qquad (1)$$

where s_1 is the total useful area of the ends of the fibers; s_0 is total area of the input end of the binder, including the intervals between the fibers; τ is the coefficient of fiber conduction; ρ is the coefficient of reflection on the ends of the fiber; U is the aperture angle at the entrance.

Depending on the temperature range, light detectors and optical fibers are selected. The advantages of an optical fiber as a structural element in the connection system are the following: the broadband up to one terohertz; small losses down to 0.154 dB/km; a fiber diameter of 125 μm; absence of cross-noise and high corrosion resistance. The transparency range of the optical fiber from quartz glass is 0.4...2.0 μm, and the temperature range is up to 2000 degrees Celsius.

The use of a sapphire optical fiber in coal burners is not justified because the emission spectra of combustion products do not fully coincide with its "window" of transparency [11]. The maximum transparency is the highest with a wavelength of 2.94 μm. A multicomponent glass fiber is made of ordinary glass with impurities of germanium oxides, lithium, and magnesium. Losses are 4 dB/km at a wavelength of 0.8 μm; the melting temperature is 1400 degrees Celsius. A plastic fiber is optimal for use in systems where a light diode is the source of light. An infrared fiber is an optical fiber with low losses in the region of infrared waves of the length from 2 to 10 μm. For the construction of an optical fiber transformer, we choose an optical fiber made of quartz glass, the transparency of which is maximal in the near-infrared radiation. An optical fiber can be used to bring an image to a television camera from several torches at the same time; the method is especially effective for color television. A promising direction is the combined use of optical fibers with mosaic light detectors.

The choice of the radiation detector is based on spectral relations, which depend on the radiation wavelengths of the individual products of the torch flame and the intensity of the background radiation, isolated by means of light interference filters. The magnitude of the electrical signals that correspond to the light flux from the flare section and the area of the background barrier is calculated by the formulae [5]

$$u_1=k_1\int_{\lambda_1}^{\lambda_2} s'_\lambda \tau_\lambda r'_{\lambda u}\,\mathrm{d}\lambda. \qquad (2)$$

$$u_2=k_2\int_{\lambda_1}^{\lambda_2} s'_\lambda \tau_\lambda r'_{\lambda\phi}\,\mathrm{d}\lambda, \qquad (3)$$

where τ_λ is the transmission coefficient of the medium; r_λ is the radiation density; s_λ is the spectral sensitivity: $s'_\lambda = s_\lambda / s_{\lambda\max}$ and $r_\lambda / r_{\lambda\max}$.

The constants k_1 and k_2 do not depend on the radiation wavelength; they mainly include the characteristics of the emitters and the optical system (s_{rad}, l_{rad}, s_t, l_t, s_{in}, $r_{\lambda\max}$), as well as some parameters of the radiative energy receiver, for example its maximum spectral sensitivity $s_{\lambda\max}$.

The values of the integrals in expressions (2) and (3) can be easily found using the simplest graph analytics methods. To do this, it is necessary to construct the dependences τ_λ, $r'_{\lambda u}$ and s'_λ. on the same scale and in relative units. Then it is necessary to construct the curves s'_λ, τ_λ, $r'_{\lambda u}$ and s'_λ, τ_λ, $r'_{\lambda\phi}$ and to find their areas Q_{u1} and Q_{u2} in the pre-selected range λ_1–λ_2. If for the same graphs there is a construction for several receivers, then by comparing the ratio of the areas Q_{u1} and Q_{u2}, it is possible to choose an optimal one among them in terms of spectral relations in the range λ_1–λ_2.

By selecting the range λ_1–λ_2 in advance, it is possible, without having to choose the receiver, to find the spectral characteristics of the transmission of the optimal filter. Taking into account the spectral characteristics, it is further possible to select the receiver according to the above methodology. In this case, it becomes immediately possible to calculate the absolute values of signals from the observed objects, from obstacles and backgrounds, that is, to find the value of the ratio m=signal/obstacle.

In modern devices for controlling the combustion (dying out) of the flame, detectors are represented by photoresistors and photodiodes with small dimensions, high sensitivity, and reduced power supply [5]. The disadvantage of photoconductors is increased inertia, dependence of their parameters on temperature, and insufficient linearity of light characteristics. Photodiodes are made of germanium and silicon. Silicon diodes are more stable in germanium at changing temperature, humidity, and pressure. The integral sensitivity of silicon diodes reaches 7 mA/lm, which is three times greater than the germanium sensitivity. To control the combustion process, it is better to use avalanche silicon diodes in a photovoltaic mode or mosaic matrices. It is better to adjust the sensors to the variable component of radiation, which helps eliminate the effect of constant radiation from the heated surfaces of the walls.

The protective tube of the device is introduced into the combustion chamber through the wall of the furnace and is installed at an angle close to 15 degrees facing the torch. Increasing UV radiation indicates an increase in temperature, and an increase in the infrared component means incomplete combustion of fuel. In low-power furnaces, the choice of the integral radiation of the furnace walls as a reference signal is not reliable because the total intensity is very much dependent on the mode of each individual burner. In large furnaces, the torches flutter well to differ from the walls of the furnace, the radiation of which practically has no fluctuation. The spectral sensitivity of the main photodetectors is in the region of 2.0–3.0 μm. For increased sensitivity, the photodiodes can be equipped with an electronic thermostat to maintain a temperature of about 20 degrees Celsius with an accuracy of 0.5 degrees.

4. 4. An electronic block diagram

Study [9] provides a scheme of temperature control by the spectral optical method. The disadvantage of the proposed scheme is the absence of automatic measurement correction depending on the concentration of secondary combustion products.

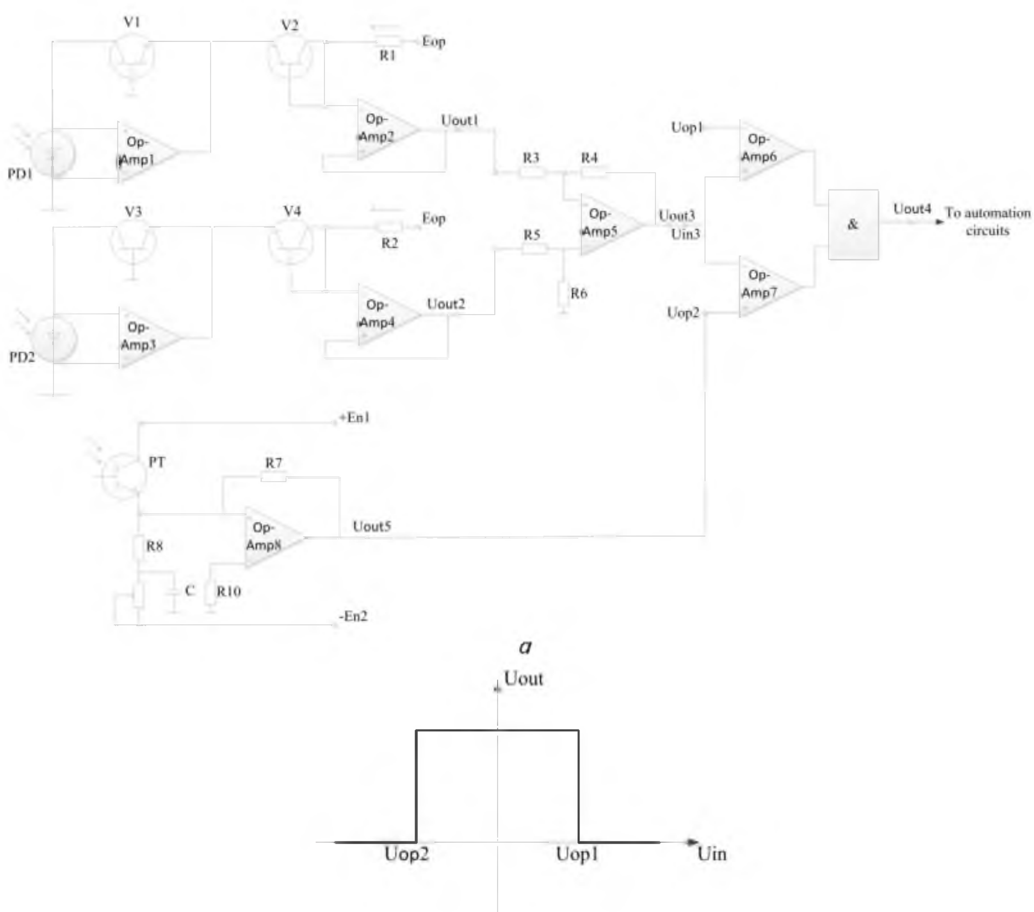
Article [12] proposes to use artificial vibrations of the burner radiation and registration in the spectrum of 470–630 nm. The images are digitized and compared in time, and area changes determine the degree of the flame propagation. This solution complicates the design and reduces the speed of the device. For the processing of optical information, a remote electronic unit (Fig. 2, *a*) is developed to consist of light detectors, amplifiers, as well as logic and output blocks. Optical fibers are collected in a drum and divided into three groups, which, by means of interference filters, emit radiation with wavelengths λ_1, λ_2, and λ_3. These components of radiation come to the converters of light streams of photodiodes PD1 and PD2 as well as phototransistor PT. In order to determine the ratio of the two components of the combustion products, the flowchart is supplied with two logarithmic amplifiers of thermal compensation with the help of additional transistors V2 and V4.

The flowchart of the electronic unit of the flame brightness control device and the output characteristics of the logic block are shown in Fig. 2.

These components of infrared radiation are applied to light signal detectors – photodiodes and phototransistors, which in Fig. 2 are marked as PD1, PD2, and V1. In order to determine the ratio of the radiation of the two components of combustion products, two logarithmic amplifiers are introduced in the circuit on the basis of Op-Amp1 and Op-Amp3 with thermal compensation with the help of additional transistors V2 and V4. The output voltage for this circuit is determined by the formula

$$U_{out} = -\varphi \ln I_{PD} / I_{com1}, \quad (4)$$

where I_{com1} is a compensation circuit that can be set using a resistor R1 [10].



b

Fig. 2. The device to control fire brightness: *a* – the circuit of the electronic unit; *b* – the initial characteristics of the logic block

The ratio of the input voltage from the light detectors PD1 and PD2 is determined by the formula

$$\frac{U_{PD1}}{U_{PD2}} = \ln(U_{out} - U_{out2}). \quad (5)$$

The algorithm of calculation can be done using a differential amplifier based on Op-Amp5. Its output voltage is regulated using R3 to correct the effect of CO_2 on the accuracy of the intensity measurements of the ratio λ_1/λ_2 of the photodiodes PD1 and PD2.

The output voltage is determined by the formula

$$U_{out} = \frac{R2}{R1}(U_{in2} - U_{in1}), \quad (6)$$

where $R1 \cdot R2 = R2 \cdot R3$ [5].

The logic output block is introduced to isolate the insensitivity zone, which has to be provided with hardware. Another introduction is the input voltage device of the "less, norm, more" type based on operational amplifiers Op-Amp6 and Op-Amp7. By changing the levels of the reference signals $U_{op\text{-}amp1}$ and $U_{op\text{-}amp2}$, it is possible to form the required width of the "window" on the original characteristics of the device (Fig. 2, *b*) [10]. The reference voltage *U*op-amp1 can be considered constant, and the width of the "window" is measured from it. The photoamplifier Op-Amp8 with a phototransistor PT measures the radiation intensity of interference products with a wavelength λ_3.

The output voltage of the photoamplifier Op-Amp8 is determined by the formula:

$$U_{out} = -R1 I_{R1}, \quad (7)$$

where I_{R1} is the current flowing through R1 [10].

The output voltage of the photoamplifier Op-Amp8 is regulated by resistor R3 and used to specify the reference voltage $U_{op\text{-}amp2}$ at the input of Op-Amp6 to correct the impact of interfering combustion products on the accuracy of determining the relationship between the radiation intensity of the main combustion products. The output of the logic element "*I*" is connected to the circuits of automatic control of the combustion process.

5. Discussion of the research results of the design of the proposed device

The use of high-temperature glass fibers for transmitting an optical image of a torch makes it possible to bring the photodetector closer to the control point, where the temperature is more than 1500 degrees. When approaching the optical input of the sensor to the torch, the effect of combustion products and the neighboring burners on the accuracy of the control is reduced. In [3], it is suggested to heat the input end of the fiber sensor to the flame temperature and introduce it as a secondary source of radiation. Sensors D-LE 703 are produced by DURAG GROUP (Germany) with a long flexible optical fiber whose viewing angle is 6 degrees [6]. Both variants provide control of the flame on a small surface of the torch. A well-adjusted torch has a length of 0.8 m and is subject to turbulent effects all the time. The advantage of using an optical fiber transformer developed in this study is that it provides control of a much larger surface of the flame than the previous designs, which increases the accuracy of the control.

Known optoelectronic sensors usually have two optical channels that control the brightness of the radiation of two different combustion products and then, in relation to these measurements, determine whether the burner is burning or dying out. The proposed device is equipped with a third measuring channel for the constant compensation of radiation products that affect the accuracy of the control. The logic output block provides a zone of insensitivity, which allows selecting a "window" in the initial characteristics of the device to configure the device in furnaces with different burner locations and different operating temperatures.

The advantages of this design are the following:

– the use of optical fiber has brought the sensor inlet to the control zone, which has reduced the effect of the layer of smoke and water vaporization;

– the optical fiber transformer allows simultaneous control of the large surface of different parts of the torch;

– the design of the device and the electronic circuitry allow for the automatic correction of the radiation exposure of the combustion products that interfere with the control of the radiation of the main compounds.

The disadvantages of this work are the lack of research of the device in the real burners of steam boilers with different variants of the location of the burners, as well as the lack of a new trace element in the electronic circuit of the device.

The design of the fiber optic transformer and the main blocks of the electronic unit can be used to develop a series of combustion control devices for coal burners. In addition, the device can be used to control the process of agglomerate sintering [13].

This work is a continuation of the development of gamma-methods for controlling the ash content of coal on the conveyor, as well as the sensors of the total combustion of coal at Zelenodolsk TPP (Ukraine). There is a need to complete the proposed device constructively.

In further research, it is possible to use the sensitivity of the optical fiber directly to the temperature and to abandon the use of photodiodes and semiconductor matrices as infrared radiation detectors. To determine the temperature value of the sensors in the form of an optical fiber, the devices used are, in particular, Mach-Zender and Fabri-Perot interferometers. The basis of these methods is the thermal deformation of the optical fiber, as well as the fluctuation and intensity of the interference of light.

The selectivity of the device may not be sufficient when the burner is arranged in the opposite position. In this geometry, each burner must have its own control device the output of which will be connected to the output of the opposite device through a comparison circuit. Such a scheme will uniquely identify any fading burner.

The adaptation of the device in case when the coal torch goes out and the combined burner switches to combustion of gas or black fuel oil has not been considered. To do this, it will be necessary to calibrate the device on the radiation spectrum of another fuel and to provide for the automatic transfer of the device to a new measurement mode.

6. Conclusions

1. The analysis of the infrared radiation spectra of combustion products has shown that the accuracy of the control

is influenced by the amount and size of carbon particles, which depends on the temperature of combustion.

2. The study has developed a functional scheme of the device to control fire brightness. The main element of the device is the design of an optical fiber transformer that provides simultaneous control of individual sections of the flame and the entire surface as a whole.

3. The findings have substantiated the principle of the device operation based on the automatic introduction of the correction for the concentration of products that hinder the accurate calculation of the ratio of the main products of combustion.

4. An electronic block scheme has been developed to control the burner's operation according to the ratio of combustion product spectra, and the logic output block has a "window" for adjusting the device the characteristics of which depend on the furnace temperature and the location of the burners.

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ABSTRACT AND REFERENCES

ENERGY-SAVING TECHNOLOGIES AND EQUIPMENT

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PARAMETRIC IDENTIFICATION OF FUZZY MODEL FOR POWER TRANSFORMER BASED ON REAL OPERATION DATA (p. 4-10)

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The research is devoted to the development of a fuzzy model for assessing the technical condition of power oil transformers based on the DGA. The parametric identification of optimal values of membership functions of fuzzy terms for linguistic variables is carried out to increase the reliability and objectivity of fault identification. For this purpose, it is proposed to use the theory of fuzzy sets, the nonlinear optimization method. A comparative analysis of the fuzzy simulation results for the technical condition with the fault diagnostic results on existing power transformers has confirmed high efficiency. The diagnostic accuracy of the adapted fuzzy model for the technical condition assessment of power transformers is 97 %, which is acceptable in the power transformers diagnostic. The developed model will be used for further research on the development of an algorithm for making effective decisions regarding the operation strategy of power transformers and preventive control of the subsystem operation of electric power systems. The obtained results of the fuzzy simulation for the technical condition assessment of power transformers give grounds to assert regarding the possibility of implementation in software of operation risk analysis of electric power systems for power supply companies.

Keywords: power transformer, dissolved gas analysis (DGA), technical condition assessment, fuzzy model, membership function.

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DETERMINING ENERGY-EFFICIENT OPERATION MODES OF THE PROPULSION ELECTRICAL MOTOR OF AN AUTONOMOUS SWIMMING APPARATUS (p. 11-16)

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Ensuring the maximum possible navigation range and duration of autonomous functioning of an unmanned swimming apparatus for special purposes was solved by minimizing energy consumption of the electromotive system. In order to achieve it, we proposed a procedure for the estimation of power losses at different static loads and power voltage of the asynchronous baro-unloaded motor of an autonomous swimming device. Special features of the procedure include determining an essentially descending character, loading characteristics of a baro-unloaded asynchronous motor of low capacity; determining the values for magnetic flux of the induction motor, at which under steady operational modes and a partial load, the total power losses are minimal; establishing dependences of performance efficiency and the stator current when controlling voltage at different loads.

Employing the proposed procedure in the control algorithm over electromotive system of the device made it possible to enable an energy-efficient change in power voltage at a constant frequency and partial loads.

Keywords: autonomous swimming apparatus, control algorithms, power losses, baro-unloaded propulsion asynchronous electrical motor.

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ANALYSIS OF THE POSSIBILITY TO CONTROL THE INERTIA OF THE THERMOELECTRIC COOLER (p. 17-24)

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We examined a model of transient processes for the thermoelectric cooler and performed its analysis when the device operated under a non-stationary mode. It is shown that the consideration of various factors influencing the transition process of a thermoelectric cooler comes down to the control over temperature of a thermoelement junction and to the variation of a heat load. The developed model connects thermophysical and structural parameters of the thermoelement, external load and operating current. The model employs the constraints: branches of thermoelements possess identical thermophysical parameters, side surfaces of the cooler are thermally insulated.

An analysis of the model revealed the influence of working current density on the temperature difference and the inertia of thermoelements. We determined conditions under which, by changing the magnitude of operating current, it is possible to minimize the time of transition of temperature difference of the thermoelement to the stationary state, typical of the systems for ensuring heat regimes of thermally-loaded components. The results obtained could serve as a basis for the creation of control system over dynamic characteristics of the thermoelectric cooler.

Keywords: thermoelectric cooler, non-stationary mode, temperature difference, control over inertia.

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ESTIMATION OF GAS LOSSES BASED ON THE CHARACTERISTIC OF THE STATE OF WELLS OF DASHAVA STORAGE (p. 25-32)

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In the present research, it is proposed to use the methods of mathematical modeling of filtering flow taking into account a special type of boundary conditions, characteristic for underground storages, peculiarities of geometry and variable characteristics of permeability of the medium, viscosity and density of fluid.

The specified models found numerical implementation using the over-relaxation method for the Dirichlet problem with a special type of boundary conditions.

As a result of the performed calculations, it was found that regardless of the model of filtering flow and the number of zones of fluid penetration through the boundary zone, the impact of existence of these zones is tangible only in the vicinity of these zones, i. e. existence of outflows on the height of the well's area almost does not affect parameters of the stream at the bottom of this area, the difference in the calculation results is less than 0.5 %. This makes it possible to conclude that detection of the outflow coordinate, as well as of the fact of its existence, is impossible within the Darcy and Forchheimer models.

Keywords: underground storage, modeling of processes, development wells, gas cross-flow, filtering process.

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DEVELOPMENT OF AN IMPROVED DEVICE TO CONTROL FLAME BRIGHTNESS IN COMBUSTION CHAMBERS OF STEAM BOILERS (p. 33-39)

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The study has helped create a device by developing the design of a sensor to control the fire brightness of a coal burner as well as by using the electronic circuit of an information processing unit. The proposed optical fiber transformer design provides a comparison of the brightness of adjacent areas and the total area of a separate torch, and it increases the viewing angle of the sensor up to 20 degrees. A third channel has been introduced to correct measurements, taking into account the radiation of combustion products that hinder the accuracy of the measurement. The study has determined the radiation spectrum of combustion products in the furnace and their dependence on the temperature of the flame.

It has been revealed that the developed optical fiber sensor increases the area of the controlled flame, which increases the accuracy of control. The presence of a "window" in the logic source block will help adapt the device to the temperature and location of burners in the furnace.

The design of the optical fiber transformer and some nodes of the electronic unit can be used in the development of serial combustion control devices for coal burners. The use of CCD matrices will help achieve future two-coordinate control of the burner flame and increase the selectivity and performance of the device.

Keywords: torch, burner, optical control, combustion products, pulverized fuel, spectrum, furnace.

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FRACTAL DIAGNOSTICS OF THE DEGREE OF FUEL ATOMIZATION BY DIESEL ENGINE INJECTORS (p. 40-46)

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The work deals with the research related to finding the relationship between the wear rate of diesel engine injector nozzles and the fractal characteristics of spots of fuel atomized by such injectors.

At present, the processes of diagnosing the degree of fuel atomization by injectors are carried out either using too complicated and expensive methods, or at a basic, visual level with conclusions about the injector efficiency. Based on the analysis of the methods of diagnostics of diesel engine injectors, the method of fractal diagnostics, which does not require the verification of elements either on a working engine, or with the use of complex and expensive devices is proposed.

The research has shown the effectiveness of the proposed quantitative fractal diagnostics to assess the wear rate of diesel engine injector nozzles. The proposed method of fractal diagnostics of the degree of fuel atomization by injectors can be divided into the following stages: getting an image of the spot of fuel atomized by an injector, allocation of the area for the fractal analysis and dimensioning, image segmentation, generation of features and comparison with the reference image.

The experimental research using the method of fractal diagnostics of the degree of fuel atomization by diesel engine injectors is carried out. On the basis of experimental data, the fractal dimension of the spot of fuel atomized by the diagnosed injector allows drawing conclusions about the readiness of injector operation on an engine or about the need for repairing such an injector.

Keywords: fractal diagnostics, degree of fuel atomization, injector, fractal modeling, computer model support.

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STUDY INTO EFFECTS OF A MICROWAVE FIELD ON THE PLANT TISSUE (p. 47-54)

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We report results of experimental research into effects of heat treatment of different plant materials in a microwave field. The effects of seed bio-stimulation are investigated, as well as features of drying and the influence of thermal treatment on the properties of moistened straw. A procedure is proposed for calculating a threshold time of seed exposure to a microwave field, compiled on the basis of hypothesis on the emergence of a bio-stimulation effect. We identified a cascade pressure growth in a container with humid grain when the layer's temperature exceeds 70 °C. The moisturizing effect of the lower layer of grain was established during its drying in MW field under conditions of a leakproof bottom. It is shown that at an initial moisture content in grain of 20 %, after 14 minutes of drying, the moisture content of the upper layer reached 15.5 %, of the middle layer – 14.5 %, of the lower layer – 21.6 %.

It was established that performance efficiency of a microwave chamber substantially depends on the loading volume, material's type, and moisture content. The chamber's performance efficiency while heating water can reach 90 %, the chamber's performance efficiency when loaded with grain does not exceed 67 %. To estimate energy effectiveness of using microwave energy, a dependence is proposed, which includes power output of the magnetron, load volume, and the value of performance efficiency. Dependences for the calculation of performance efficiency when loading a material are proposed to be established experimentally.

Keywords: microwave energy, heating, plant tissue, bio-stimulation, drying, performance efficiency.

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INFLUENCE OF IMPURITIES IN PROPANE COOLANT ON THE PROCESS OF OBTAINING ARTIFICIAL COLD (p. 55-62)

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The study of the influence of propane quality on the total pressure of vapors of the coolant in condensation and vaporization processes and on operation of refrigeration equipment was carried out.

Research was carried out in the refrigeration department of the industrial combined unit of deparaffination of raffinates and oil removal from gatch. In the experiment, technical propane with the content of the main component of 91–96 % by weight was used as the coolant, the rest was made up by hydrocarbon impurities. To determine the composition of the coolant, chromatographic method for separation of hydrocarbons was used.

The impact of propane quality on total pressure of coolant vapor in the refrigeration cycle was determined. Impurities were found to contribute to an increase in total pressure and temperature in evaporation and condensation processes.

A decrease in propane content in the coolant from 95 % by weight to 89 % by weight leads to an increase in pressure in condensers from 57 to 86 kPa, in condensers – from 1,385 to 1,524 kPa. At the same time, there is an increase in temperature of evaporation and condensation by 4–5 °C.

Contribution of each separate impurity to total pressure of saturated vapors of the coolant in evaporators and condensers was determined. The most harmful impurities are ethane and butane. Ethane and methane under conditions of cold production are in gaseous state and increase total pressure in the refrigeration cycle. The content of methane in the raw material mixture does not exceed 0.03 % by weight, which is why its impact on total pressure is negligible.

Butanes form a liquid film on the surface of the equipment, worsen heat exchange processes, and contribute to an increase in the total pressure.

Propylene behaves in the system as a coolant and its impact on total pressure is insignificant.

The impact of hydrocarbon impurities on operation of refrigeration department was established. The impurities differently affect operation of the equipment, however, on the whole, this impact is negative.

An increase in amount of impurities in the coolant contributes to an increase in power consumption of the compressor, worsens compression process and increases consumption of electricity.

A decrease in propane content in the raw material mixture from 97 % to 95 % leads to an increase in total thermal loading on the condenser and the refrigerator by 1.7 %. This causes additional material and energy consumption in the course of cold production.

Keywords: refrigeration unit, refrigeration equipment, propane coolant, hydrocarbon impurities, vapor pressure.

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