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AUTOMATED SYSTEM FOR CONTROL AND MONITORING OF EXPLOSION SAFETY OF THE COAL GRINDING PROCESS IN BALL DRUM MILLS

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Abstract. The article presents the results of research on automated systems of control and monitoring of explosion safety of dust and gas mixture during coal grinding in ball drum mills (BDM). The problem of the gas-dynamic factor, which arises at the disintegration of coals of middle stage of metamorphism (gas coals) in the atmosphere of closed or limited space, for example in mine workings, chambers, furnace furnaces, etc., is considered. Earlier, when burning anthracite coals, such a problem did not arise, since anthracite does not have a gas component of hydrocarbons. Therefore, all automated control systems were developed from the condition of grinding quality and optimal loading of the BDM. The work aims to develop an automated system of control and monitoring of explosion safety of coal-gas mixture in ball drum mills in the process of grinding gas coals in preparation for combustion. It is established that the sizes of coal grinding fractions in the BDMs from 50 microns to 250 microns correspond to the sizes of supermelonites from 10 microns to 200 microns to particles that are formed during sudden coal and gas emissions in mines. Coal supermelonites are the main source of gas emission into the atmosphere of mine workings, as at their formation there is the disintegration of the supramolecular organization of coal macromolecule and generation of methane. Crushing of gas coals in the BDM inevitably leads to the formation of the explosive methane-coal mixture, which further enters the furnace of the boiler unit. As a result, a new functional scheme for automatic regulation and optimization of parameters of the BDM with a measuring and computing system for controlling the temperature of the gas medium, pressure drop, and a self-tuning microprocessor controller was developed. A technological scheme for installing control and measuring equipment has been developed for preparing coal for burning in a thermal power plant boiler unit. Explosion safety control in the technological cycle of preparing gas coals for burning is carried out constantly using methane and oxygen concentration sensors. The operability of the control system was confirmed on the industrial mill of the boiler unit BKZ-160-100PT TPP of "Kramatorskteploenergo" TPP.

Keywords: ball drum mill, coal grinding, methane, explosion safety, control system.

1. Introduction

The process of coal grinding in ball drum mills (BDM) for its subsequent combustion in boiler units at thermal power plant (TPP) or other solid fuel combustion plants is associated with the need to control the quality of coal grinding and filling of the mill drum. The study of the parameters of these processes has been going on for many decades and has sufficient scientific and technical substantiation. Both schemes and systems of automated control of the processes of crushing and filling of the mill drum have been developed [1–5]. The modes of dynamic processes of the BDM operation are investigated and modeled [6–8].

Particular attention is paid to solving problems of explosion and fire hazards of coal dust in the process of coal grinding and fuel combustion. The urgency of this problem has increased in connection with the transition to combustion in boiler units of coals of the middle stage of metamorphism. It is connected with the fact that to the problem of spontaneous combustion and explosion of fine dust particles of coal [9–16] the gas factor was added, which earlier in the process of coal pulverization in BDM was absent and was not investigated.

Specialists, connected with the solution of the problem of gas dynamic factor at coal mines, know that fine-dispersed destruction of coals at gas dynamic phenomena is accompanied by catastrophic increased gas emission into the atmosphere of mine workings [12, 13, 16]. The more the mass of the ejected coal particles of the size from 10 microns to 250 microns (supermelonites), the greater the energy of ejection and the greater the volume of gas emission into the mined-out space. It is established that at coal destruction to the phase of supermelonites, structural changes occur in the supramolecular organization (SMO) of coal substance, namely in its aliphatic part. Breaking of connections between structural elements of SMO leads to new formations. So, at the destruction of the supermelonitic phase of coal macromolecule of coal substances of "D" and "G" grades can generate from 2 to 5 molecules of water and methane, and of "G" and "K" grades 5 molecules of water and from 9 to 14 molecules of methane [16].

In the technological cycle of preparation of coal for combustion, it is pre-crushed into grains of size from 8 to 10 mm and then pulverized in ball mills to a finely dispersed state from 50 microns to 200 microns. Such process of coals preparation for combustion, especially in the middle stage of metamorphism, leads to formation of dust and gas mixture prone to oxidation and self-ignition. According to the information of the boiler unit operating personnel the cases of self-ignition and explosions of dust and gas mixture take place, but they are not recorded. The operation control and safety services do not investigate them. Therefore, there are no registered cases of the negative influence of the gas factor on the coal grinding process. At the same time, it indicates that the problem of the gas-dynamic factor already exists, and scientifically grounded ways of its control in the control system of the process of coal grinding in BDM are absent.

First of all, it is connected with an imperfection or lack of methods and means of measuring parameters of a coal-gas medium in the process of coal grinding in the mill drum. Secondly, based on the experience of production activity of the enterprises and state control bodies, this problem will not be considered and solved at the scientific and technical level before the manifestation of the explosion of the methane-coal mixture in the mill of destructive force. Thirdly, the developed automated methods of control systems of the coal grinding process do not provide for control of gas emission and methane concentration in the BDM. Fourthly, to reduce the probability of fire and explosion hazards in a dust and gas environment, exhaust gases are fed into the mill drum together with heated air. This allows for to reduction of the oxygen content in the gas environment of the BDM but does not exclude the risks of methane ignition and dust explosion during the fine grinding of coal.

In this connection, the purpose of this work is to develop an automated system of control of explosion safety of coal-gas mixture in ball drum mills in the process of grinding of gas coals during their preparation for combustion.

To achieve the goal of the work the following tasks were solved:

1. Analysis and establishment of parameters of control of explosion safety of coal-gas mixture in the BDMs in the process of grinding of gas coals.

2. Establishment of safety criteria and ranges of methane and oxygen concentrations in the dust and gas mixture in the mill drum.

3. Development of the control system of the parameters of the technological cycle of coal grinding.

4. Adaptation of the control system of dust and gas mixture parameters in the system of automatic control of the process of feeding and grinding of raw materials.

The solution of the set tasks allows optimization of the parameters of the process of coal grinding in BDM to improve technical and economic performance and safe operation of TPP.

2. Experimental methods

In the research are used: method of experimental analysis of results of work of ball drum mills at various volumes of their loading by coal of various marks; method of mathematical modeling of process of control of work of BDM for the decision of problems in information-controlled spaces of technological processes; research and the analysis of energy-saving and explosion safety of work of BDM in the process of industrial operation at Kramatorskteploenergo TPP.

3. Theoretical part

Considering the results of automated control of pulverizer operation and safety of the grinding process, we conclude that in the functional schemes and control systems of automatic process control system (APCS), there are no devices and equipment for controlling the content of gases CH_4 and O_2, temperature *T,* and pressure *P*. Control of these parameters in the preparation of gas-grade coals for combustion in boiler units is a technological necessity. Therefore, based on the existing technical and technological conditions for observance of the safety of the coal grinding process and fuel combustion a new functional scheme of automatic regulation and optimization of parameters of BDM has been developed (Fig. 1).

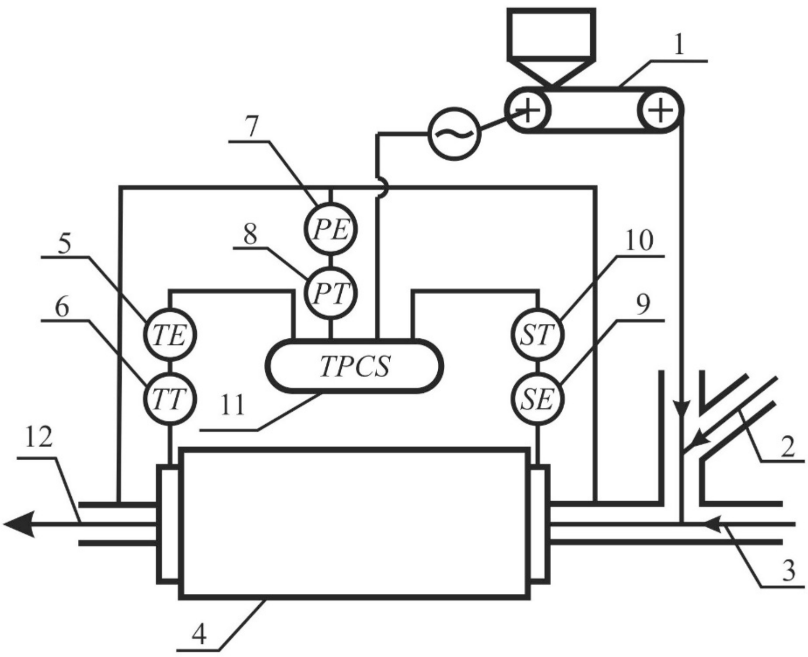

Figure 1 – Functional scheme of automatic regulation and optimization of ball drum mill parameters

In the technological scheme of coal grinding, which includes: 1 – raw coal feeder; 2 – return from the separator; 3 – drying agent; 4 – ball drum mill; 5, 6 – primary and secondary measuring transducers of coal-gas medium temperature at the mill outlet;

7, 8 – primary and secondary measuring transducers of pressure drop on the mill drum; 9, 10 – measuring transducers of mill loading: primary (accelerometer) and secondary (conversion unit BP-6); 11 – self-adjusting microprocessor controller.

Based on the new functional scheme, the technological scheme of installation of control and measuring equipment during the preparation of coal for combustion in the boiler unit of TPP is developed (Fig. 2).

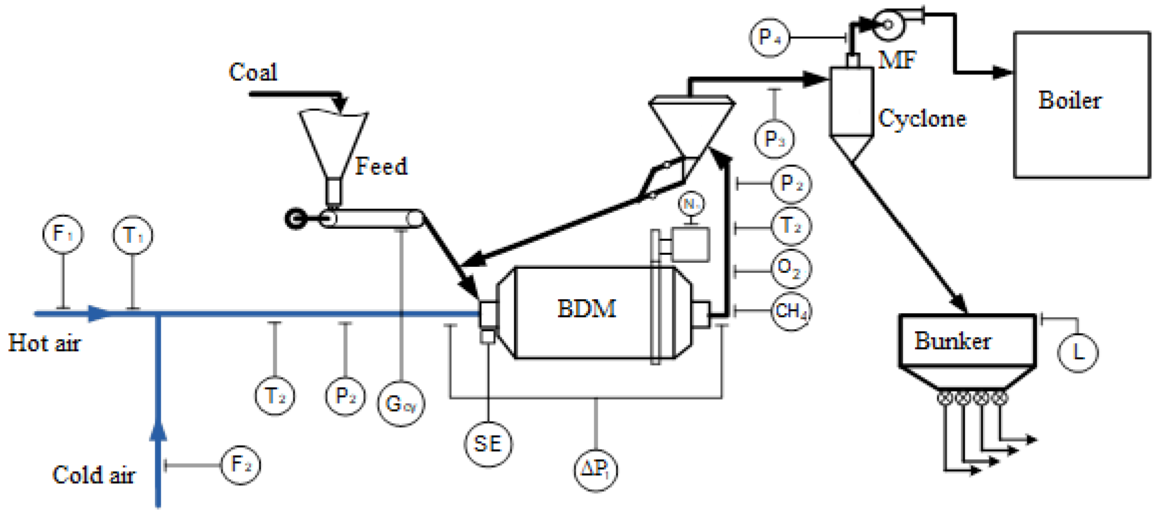

Figure 2 – Scheme of installation of control and measuring equipment on the BDM during preparation of coal of gas grades for combustion in the boiler unit of TPPs

On the scheme, it is marked: G – raw coal consumption for grinding, t/h; F_1 – hot air flow rate in the mill drum m^3/h; F_2 – cold air flow rate in the mill drum, m^3/h; N – power consumed by the electric drive of the mill drum, kWh; T_1 – temperature of hot air in front of the mill drum, ºC; T_2 – temperature of cold air in front of the ball mill, ºC; T_3 – temperature of coal-gas mixture at the outlet of the ball mill, ºC; P_1 – air rarefaction in front of the ball mill, mm H_2O; P_2 – rarefaction of the coal-gas mixture after BDM, mm H_2O; ΔP_1 – pressure drop on BDM, mm H_2O; P_3 – rarefaction of coal-gas mixture after separator, mm H_2O; MF – mill fan; P_3 - rarefaction before MB, mm H_2O; CH_4 – methane concentration sensor, %; O_2 – oxygen concentration sensor, %.

A new scientific and technical solution in the automated process control system of the BDM is continuous control of explosion safety of dust and gas fuel sludge with the help of sensors of methane and oxygen concentration in the technological cycle of preparation of gas coals for combustion (Fig. 2).

In the process of solving the set tasks the functional scheme of the measuring and computing system of control and monitoring of explosion safety of dust and gas mixture during coal grinding in ball drum mills was developed (Fig. 3). The developed control system allows to use both operational parameters and parameters of regulators of the measuring-computer control system of the coal grinding process.

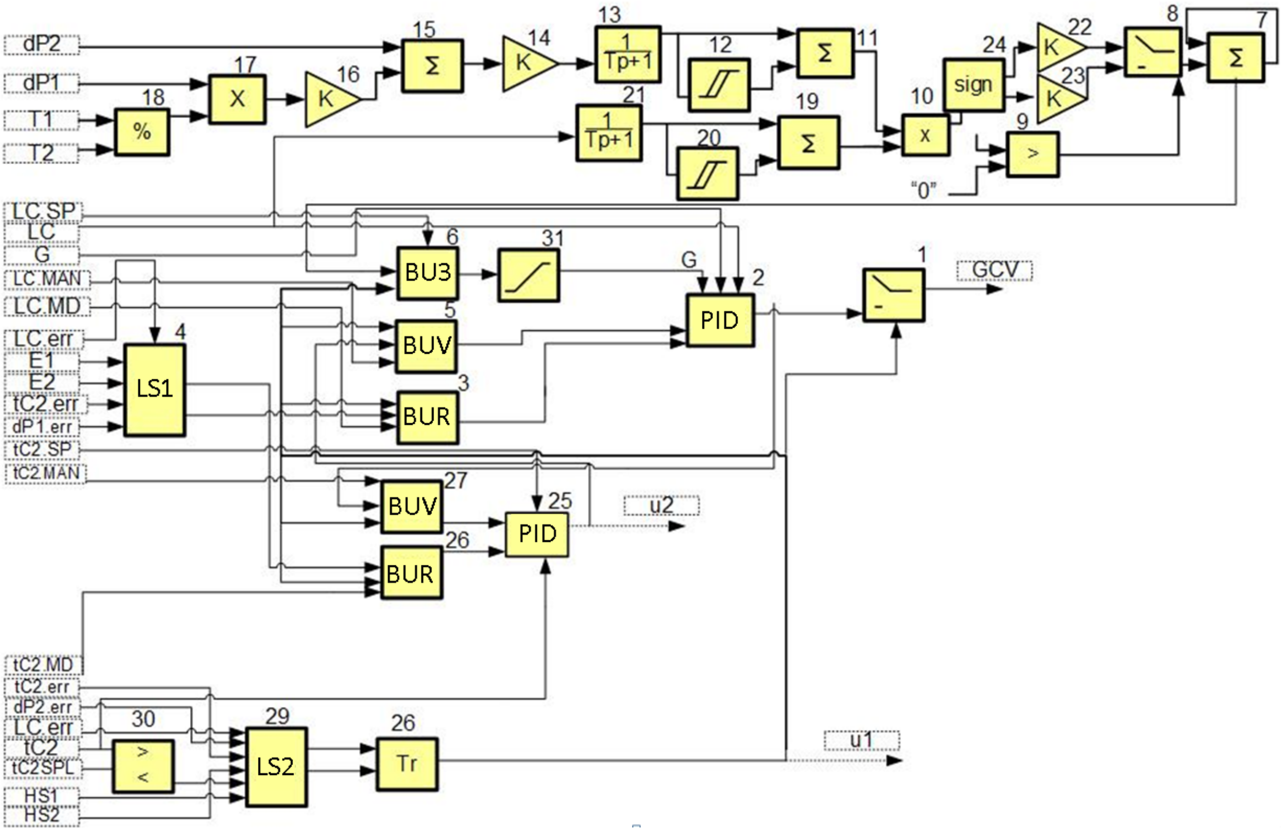

Figure 3 – Functional diagram of the measuring-computer system of control and monitoring of explosion safety during operation of the BDM

Additional operational parameters are used:

dP1 – dynamic airhead before the mill, Pa;

dP2 – dynamic pressure of dust-air mixture after the mill, Pa;

T1 – absolute temperature of the air before the mill, ^oK;

LC – level of mill loading with raw material, %;

LC, SP, tC2.SP – assignment to regulators, %;

LC.MAN, tC2.MAN – setting for the output signal of regulators, %;

LC.MD, tC2.MD – regulators mode;

G1 – raw material flow rate to the mill, t/h;

tC2.SPL – setpoints of the minimum temperature of the dust-air mixture after the mill, %;

T1.err, dp1.err, tC2.err, LC.err – diagnostic signals;

E1 – mill stop signal;

E2 – a signal of raw material supply to stop to the mill;

tC2 – temperature of the dust-air mixture after the mill, ^oC;

HS1 – switch on/off the mill loading limitation mode according to the minimum temperature of the dust-air mixture after the mill;

HS2 – switch of the active regulator (LC-tC2).

The recorded values of operating parameters are fixed by measuring converters of computing devices and are corrected by regulators by:

- measurement of air temperature in front of the mill;

- measurement of a dynamic airhead in front of the mill;
- measurement of the dynamic head, methane, and oxygen concentrations in the dust-air mixture after the mill;
- measurement of the level of filling of the mill drum with pulverized coal;
- measurement of coal flow rate;
- calculation of the finished product flow rate to the mill.

Further, there is a transfer of signals from measuring transducers and computing devices of the mentioned parameters to the measuring and computing control system.

Control of the coal grinding process is accompanied by the following operations:

- regulation of the mill loading employing the level controller;
- regulation of mill productivity with the help of loading level indicator and finished product output;
- creation of the mode of inadmissibility of moisture in the finished product by limiting the temperature of the dust-air mixture after the mill;
- automatic stopping of coal supply in case of explosion hazard of the dust-air mixture and stopping the mill;
- manual activation and deactivation of the loading limitation mode at the minimum value of the dust-air mixture temperature after the mill;
- manual selection of the active regulator;
- mill loading control with the help of a level regulator in case of failure of measuring device of dust-air mixture temperature after the mill;
- automatic transfer of the level regulator from the "Cascade" mode to the "Automatic" mode in case of failure of the measuring device of the dynamic head before or after the mill or of the air temperature at the mill inlet;
- automatic transfer of the regulator to the "Manual" mode in case of failure of the mill loading level measuring device.

Limiting the reduction of the dust-air mixture temperature after the mill tC2 below the setpoint tC2.SPL is a prerequisite for the control process. As long as the dust-air mixture temperature at the mill outlet is higher than the lower level setpoint, the mill loading is controlled by the level controller (block 2).

The temperature controller (block 25) is in the "Manual" mode, and its mode cannot be changed (block 26), and the "Output" of the temperature controller tracks the "Output" of the level controller (block 27). The level controller, in this case, can be in the "Cascade", "Automatic" or "Manual" modes. When the dust-air mixture temperature reaches the setpoint tC2.SPL (block 30), the loading is controlled by the temperature controller (blocks 1, 28, 20).

The level controller is automatically switched to the "Manual" mode (block 3), and the mode and the setpoint for it are memorized (blocks 3, 6). The temperature controller is automatically switched to the "Automatic" mode (block 26), and the driver sets the task for the temperature controller in advance (for this controller in the "Manual" mode the task does not track the variable). In this case, it is impossible to change the mode of the level controller (block 3), its "Output" tracks the "Output" of the temperature controller (block 5), and for the temperature controller the modes "Automatic" and "Manual" are achievable.

When the temperature tC2 rises to tC2.SPL + 1 °C (block 30), the level controller (blocks 1, 28, 29) starts to control the loading; the temperature controller is automatically set to "Manual" mode (block 26).

The mill loading level controller is automatically set to the mode and setpoint at the time of the previous changeover (blocks 3, 6). In this case, it is not possible to change the mode of the temperature controller, its "Output" tracks the "Output" of the level controller (block 27), and the modes "Cascade", "Automatic" and "Manual" are achievable for the level controller.

The temperature limitation is triggered when the HS1 signal has a logical value of "1" (block 29), otherwise the active controller is determined by the initial position of the HS2 switch.

The control scheme is designed to provide the maximum possible product flow rate. When the level controller (block 2) is switched to the "Cascade" mode with the help of blocks 7-24, a task is automatically formed for it that will ensure the maximum productivity of the mill. For this purpose:

- in blocks 14-18 the current product flow rate (G2) is calculated;
- in blocks 13 and 21 the current value of the product flow rate and the loading level are smoothed;
- in blocks 8-12, 19, 20, and 22 the angle of inclination of the tangent to the extreme curve LC (G2) is estimated, in connection with which in block 7 with the help of blocks 22-24 and 8 a correction to the setting of the loading level regulator is introduced.

In the case of mill stop (signal E1), the active regulator is automatically switched to the "Manual" mode (blocks 3, 26) and its "Output" value is set to "0,00" (blocks 5, 27). Thus, the feed to the mill is stopped. In case of stoppage of raw material supply to the mill (signal E2), the active regulator is automatically switched to the "Manual" mode (blocks 3, 26). In case of failure of the level measuring device (signal LC.err is logically equal to "1"); if the temperature signal tC2 is probable (signal tC2.err is logically equal to "0"), the mill feed control will be started by the tC2 controller (blocks 4, 29). Otherwise, the level controller will automatically switch to the "Manual" mode (blocks 3, 4). When the temperature measuring device tC2 fails, if it is active at that moment, one of the following phenomena will take place:

A. The switch of the active controller HS2 has a logical value of "0". The temperature controller automatically switches to the "Manual" mode (blocks 4, 26); the mill load level controller is automatically set to the mode and setpoint at the time of the previous switchover, i.e. when the LC controller was active (blocks 3, 6).

B. The switch of the active controller HS2 has a logical value of "1": the temperature controller will automatically switch to the "Manual" mode (blocks 4, 26). A smooth transition from manual to automatic mode is provided for the mill load level controller, based on limiting the rate of change of the setpoint (block 31). In case of failure of the dynamic head signals dP1 or dP2 or the mill inlet air temperature T1, if the LC controller is currently in the "Cascade" mode, it is automatically switched to the "Automatic" mode (blocks 3, 4).

According to the requirements [17, 18] in gas transportation systems, the methane concentration in the mixture of 3.5-25.0% is unacceptable. The paper [1] presents the results of studies of regularities and explosion safety criteria, which made it possible to establish the ranges of methane and oxygen concentrations in the methane-air mixture in the form of equations (1), (2) and (3):

- from 0 to 5% CH_4

$$K_{b1} = \frac{7 + \left|K_{CH} - 5\right| \cdot 2.6 - K_{O_2}}{7 + \left|K_{CH_4} - 5\right| \cdot 2.6} \cdot 20^{0.5\left[1 - Sign(7 + \left|K_{CH_4} - 5\right| \cdot 2.6 - K_{O_2})\right]}; \qquad (1)$$

- from 5 to 20 % CH_4

$$K_{b2} = \frac{7 - K_{O_2}}{7} \cdot 20^{0.5\left[1 - Sign(7 - K_{O_2})\right]}; \qquad (2)$$

- from 20 to 25% CH_4

$$K_{b1} = \frac{20 + \left(K_{CH_4} - 20\right) \cdot 1.6 - K_{O_2}}{20 + \left(K_{CH_4} - 20\right) \cdot 1.6} \cdot 20^{0.5\left[1 - Sign(20 + \left(K_{CH_4} - 20\right) \cdot 1.6 - K_{O_2})\right]}, \qquad (3)$$

where K_{b1}, K_{b2}, K_{b3} – explosion safety coefficients K_{CH4} – measured methane concentration, %; K_{O2} – measured oxygen concentration, %.

Taking into account that in the pulverizing of gas coals in the pulverizer drum methane-air medium is formed simultaneously with fine coal particles, the use of equations (1), (2), and (3) will allow us to estimate the degree of risk of explosion hazard of the pulverizing process. Thus, the control of dust and gas mixture parameters in the pulverizer in the complex functional scheme of automatic regulation and control of the process of gas coal grinding allows to study, control, and manage the explosion safety of the process.

4. Results and discussion

The control system performance was tested in industrial conditions at the mill of boiler unit BKZ-160-100PT of Kramatorskteploenergo TPP. The tests showed that the developed control method provides a long and reliable operation of the mill, excluding the possibility of its overfilling with coal coming for grinding and exceeding the safety criteria for the range of methane and oxygen concentrations in the dust and gas mixture.

The analysis of the results of industrial testing of the developed control system of the pulverization process and explosion safety control of the BDM operation allowed to establish:

- reduction of specific consumption of raw materials and unforeseen material costs;

- significantly improve the working conditions of the operating personnel and reduce losses associated with unforeseen stops and repairs of equipment;

- uniform loading of the mill stabilizes the fineness of coal dust grinding within ± 3%, which leads to the increase of efficiency of the fuel combustion process and reduces its losses with fly ash by 15%;

- the developed system of measurements of CH_4 and O_2 concentration allows for control of their content in the mill drum during coal grinding.

5. Conclusions

1. An automated system of control and monitoring of explosion safety of dust and gas mixture during grinding and combustion of medium-stage metamorphism coal by the content of fine dust, oxygen, and methane in ball drum mills in boiler units of TPPs has been created.

2. The functional scheme of automatic regulation by the system makes it possible to control the feeding of the crushed raw material into the mill drum, to exclude the probability of its blockage and to ensure explosion safety of the processes of preparation and combustion of gas-coal fuel in boiler units of TES.

3. The developed system of measurements of CH_4 and O_2 concentration allows an investigation of the parameters of equations (1), (2) and (3) taking into account their influence on the explosion safety criteria of the coal grinding process in BDM in the presence of fine gas-coal dust.

4. Implementation of the developed automatic control system allows optimization of the process of coal grinding, increases the productivity of BDM, reduces specific power consumption, stabilizes the fineness of coal grinding at the level of ± 3%, and reduces its losses with underburning up to 15%. The annual economic effect from the implementation of the automatic control system at four mills of "Kramatorskteploenergo" TPP amounted to 9917424 UAH, including 658212 UAH due to electricity savings and 9259212 UAH due to coal savings.

5. Successful experience in industrial operation of the developed system of automatic control of the grinding process allows us to recommend it for wide industrial implementation at TPPs of Ukraine.

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АВТОМАТИЗОВАНА СИСТЕМА КЕРУВАННЯ ТА КОНТРОЛЮ ВИБУХОБЕЗПЕКИ ПИЛОГАЗОВОЇ СУМІШІ ПІД ЧАС ПОДРІБНЕННЯ ВУГІЛЛЯ В КУЛЬОВИХ БАРАБАННИХ МЛИНАХ

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Анотація. У статті наведені результати досліджень автоматизованих систем керування та контролю вибухобезпеки пилогазової суміші під час подрібнення вугілля в кульових барабанних млинах (КБМ). Розглядається проблема газодинамічного чинника, що виникає під час дезінтегрування вугілля середньої стадії метаморфізму (газового вугілля) в атмосфері замкненого або обмеженого простору, наприклад, у гірничих виробках, камерах, топках печей тощо. Раніше, під час спалювання антрацитового вугілля, така проблема не виникала, оскільки в антрацитах газова складова вуглеводнів відсутня. Тому всі системи автоматизованого контролю розроблялися з умови якості помелу та оптимального завантаження барабана кульового млина. Метою роботи є розробка автоматизованої системи керування та контролю вибухобезпеки вуглегазової суміші в кульових барабанних млинах у процесі подрібнення газового вугілля під час його підготовки до спалювання. Встановлено, що розміри фракцій подрібнення вугілля в КБМ від 50 мкм до 250 мкм відповідають розмірам супермелонітів від 10 мкм до 200 мкм частинкам, що утворюються під час раптових викидів вугілля і газу в шахтах. Супермелоніти вугілля є основним джерелом газовиділення в атмосферу виробок, оскільки під час їх утворення відбувається дезінтеграція надмолекулярної організації макромолекули вугілля та генерація метану. Подрібнення газового вугілля в КБМ неминуче призводить до утворення вибухонебезпечної метановугільної суміші, яка далі надходить до топки котлоагрегату. За результатами досліджень була розроблена нова функціональна схема автоматичного регулювання та оптимізації параметрів КБМ з вимірювально-обчислювальною системою контролю температури газового середовища, перепаду тиску, мікропроцесорним регулятором, що самоналаштовується. Розроблена технологічна схема встановлення контрольно-вимірювального обладнання при підготовці вугілля до спалювання у котлоагрегаті ТЕС. Контроль вибухобезпеки у технологічному циклі підготовки газового вугілля до спалювання ведеться постійно за допомогою датчиків концентрації метану та кисню. Працездатність системи керування було підтверджено на промисловому млині котлоагрегату БКЗ-160-100ПТ ТЕС ТОВ "Краматорськтеплоенерго".

Ключові слова: кульовий барабанний млин, подрібнення вугілля, метан, вибухобезпека, система керування.