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ENERGY RESOURCES AND EXPLOSION SAFETY ENSURING OF TPP WHEN USING STATIONS CONTROL OF BALL DRUM MILL

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Abstract. Ukraine has approximately 300 to 500 ball drum mills in operation, which are used in various branches of industry. Most of them in factories works at partial capacity and on old or poorly modernized control systems. The complexity of ball drum mills control lies in various factors that affect the grinding process, namely: moisture content of raw materials, mechanical properties of the material, wear of armor plates and grinding bodies. At the same time, the influence of these factors without high-tech devices makes it difficult to control the grinding process, so with simple control systems operators work at lowered parameters for steady operation. Ball mills for grinding raw coal are considered. Experimental studies of ball drum mills operating modes in industrial conditions and on models were carried out. Mathematical models of grinding processes dynamics of raw coal were developed and research allowed to construct a system of optimal control of volumetric loading of a ball mill with stabilization of temperature of an air mix was carried out. A method of fuzzy adaptation of the controller setting parameters is proposed and rational control algorithms are chosen. Using the vibration acceleration sensor and the signals processing the volumetric load of the ball mill was calculated. The results of the study of optimal control system of ball drum mills volumetric loading showed high quality of control under various external influences. The control system allows to use the maximum performance of ball drum mill. An annual economic effect of $ 354,219 was obtained. Working design was developed, industrial tests were conducted and station control of ball drum mill was manufactured, implemented and put into operation. Parameters of explosion safety ensuring of a mill air mixture are established. The system of measurement and calculation of volume loading by coal of a drum of the rotating mill and maintenance of explosion safety of an air mixture of a mill is developed.

Keywords: energy resources, explosion safety, TPP, stations control, ball drum mill.

Introduction. Energy efficiency and explosion safety of coal-fired boilers is largely determined by the operation of ball drum mills [1, 2]. The appearance of one of the types of ball drum mills is presented in Figure 1.

Ball drum mills are used to prepare coal dust supplied to steam boilers of thermal power plants [3]. One of the most important parameters of the control of grinding raw coal process is the control of ball drum mills loading, explosion safety ensuring and stabilization of the air mixture temperature in the drum of the mill.

Figure 1 – Appearance of a ball drum mill

Temperature control is carried out by mixing atmospheric air with a part of hot flue gases or by changing the drum loading level of a ball mill with raw coal. To prevent explosions inside the ball mill, a mixture of flue gases is fed to its entrance.

It is known that the performance of ball drum mill depending on the load level has an extreme character:

$$G_2 = G_{2max}(1-(1-\frac{V}{a})^2), \tag{1}$$

where, G_2 - the productivity of a mill by coal dust, t/g; G_{2max} - the maximum productivity of a mill by coal dust at the set properties of coal and air temperature; a - the level of drum volumetric loading of the mill, corresponding to the maximum productivity; V - volumetric loading of a mill drum, m^3.

The volumetric loading of a mill drum is expressed by dependence:

$$V = k\int(G_1 - G_{2max}(1-(1-\frac{V}{a})^2))\ dt, \tag{2}$$

where, G_1 – volume flow of the dry part of raw coal supplied, t/g; k - the design factor of the mill; t – mill loading time, min.

Ball drum mill has a stable character on the ascending branch and unstable on the descending branch of the optimum productivity from volumetric loading. It should be noted that the position of the optimum is shifted when changing the raw coal humidity and its mechanical properties, which complicates the work of standard raw coal loading regulators. The characteristic of ball drum mill is presented in Figure 2. [1, 4, 5].

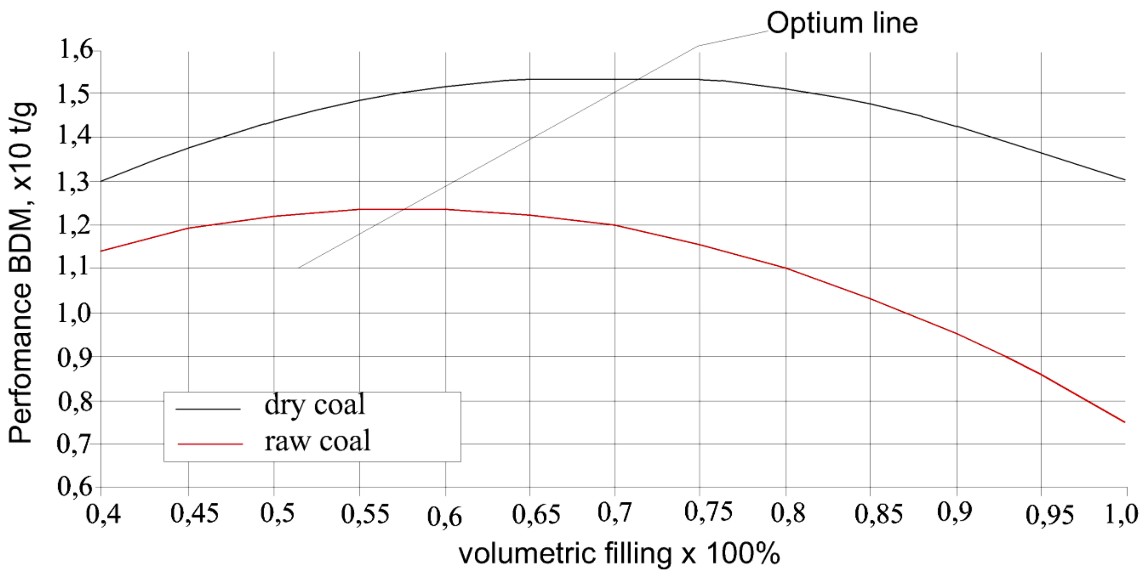


Figure 2 – Dependence of ball drum mill productivity on drum volumetric loading

The purpose of the paper is to ensure energy saving and explosion safety control of ball drum mills to achieve which requires the solution of the following tasks:

- measurement and calculation of the volumetric load of coal on the drum of a rotating mill;

- measurement and calculation of parameters of explosion safety of the air mixture of the mill;

- development of a mathematical model of the dynamics of crude coal grinding processes and conducting research that would allow to design a system of optimal control of the volumetric loading of a ball mill with stabilization of the temperature of the air mixture and ensuring its explosion safety;

- develop a working design of the ball drum mill control station and conduct its industrial tests.

Methods. The results obtained in this paper were achieved using the following methods:

- study in industrial conditions the operation parameters of ball drum mills at various volumes of coal loading, different marks and mechanical properties;

- method of Fourier expansion of vibration signals;

- the method of regularity finding between the volumetric loading of the drum and the vibration acceleration of the bearing support of ball drum mill;

- experimental study and mathematical modeling of the process;

- research and analysis of energy saving of ball drum mill operation under the control of the station "DIYA" in the process of industrial operation at Kramatorsk CHP.

To ensure steady operation of the load controller, a corrective device (CU) is used in the block of optimization (BO) [3]. Corrective device allows to carry out loading of ball drum mill in all range of volumetric filling.

BO changes the task of the volumetric load controller after the time T set by the pulse generator, according to the following algorithm [4].

$$\begin{aligned} &if \quad (G_n - G_{n-1})\cdot(V_n - V_{n-1}) > 0 \\ &\qquad V_{zn} = V_{z(n-1)} + \Delta V_z \\ &else \; V_{zn} = V_{z(n-1)} - \Delta V_z \end{aligned} \tag{3}$$

where G_n – current productivity of the mill by coal dust, t/g; G_{n-1} - preliminary productivity of a mill by coal dust, t/g; V_{zn} - the set level of the mill drum volumetric loading, m^3; $V_{z(n-1)}$ – the preset level of the mill drum volumetric loading, m^3; ΔV_z - the difference in volumetric loading of the mill drum, m^3.

Stabilization of the air mixture temperature at the output of the ball drum mill is carried out by changing the ratio of cold and hot air supplied to the mill drum. The moisture contained in raw coal evaporates under the action of hot air heat.

The flow of steamed moisture F_w (m^3/h) is determined by the following formula

$$F_w = \frac{100 - w}{100} \cdot G \cdot \frac{1}{p}, \tag{4}$$

where w – moisture of raw coal, %; G – consumption of raw coal kg/g;
ρ – vapor density at air mixture temperature T_2, kg/m^3.

Due to the evaporation of raw coal moisture, the flow of hot air at a constant performance of the mill fan will decrease by F_w

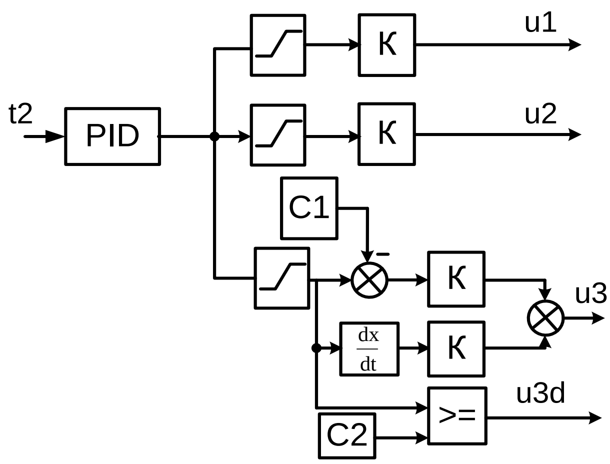
$$F_1 = F_{mv} \cdot \frac{T_2}{T_0} / - F_w, \quad (5)$$

where F_{mw} - the installed capacity of the mill fan m^3/g; T_2 – the absolute temperature of the air mixture at the ball drum mill output, °C; T_0 – the temperature of the air mixture at the output of the ball drum mill under normal conditions, °C.

The latter leads to a decrease in the amount of evaporating moisture and the air mixture temperature at the mill drum output. Temperature stabilization is carried out by reducing the load of raw coal. To prevent a decrease in the temperature of the air mixture and the ball drum mill productivity with raw coal humidity increasing, it is necessary to increase the heat supply by the amount required to evaporate additional moisture. Thus, the temperature can be stabilized sequentially by three control effects:

1. Changing the flow of cold air u_1 at low humidity;
2. Increasing the productivity of mill fan u_2 to the limit value;
3. Changing the flow of raw coal u_3 for grinding.

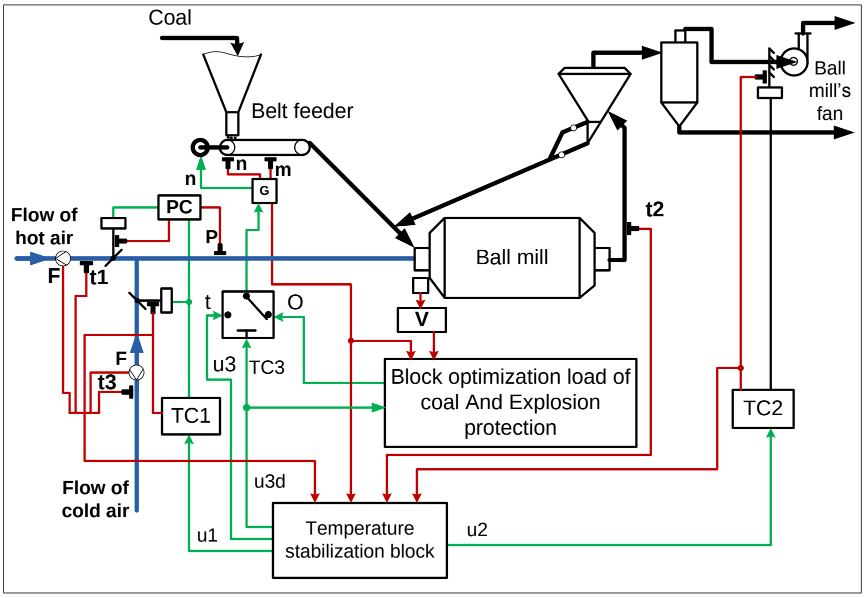
Figure 3 shows a block diagram of the output unit of the temperature controller, which implements the above control effect of the actuators [6]



t_2 - the temperature of the air mixture at the mill drum output, °C; PID – proportionally integrated link; C_1 – moisture factor of raw coal; K – acceleration factor; C_2 – dry coal factor; u_{3d} – the task of raw coal flow reducing

Figure 3 – Diagram of the output unit of the temperature controller

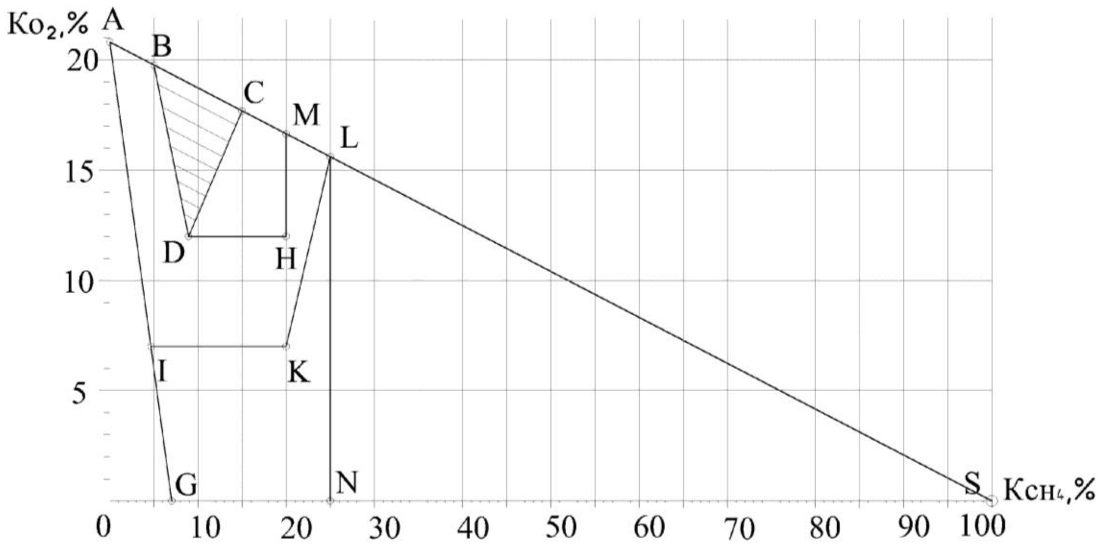
When switching the controller to control the supply of raw coal, coal signal u_{3d} switches the BO to the mode of load limiting on the air mixture temperature. The developed unit is used in the system of optimal control of volumetric loading of ball drum mill with explosion safety and temperature stabilization of the air mixture, the functional diagram of which is presented in Figure 4.



t_2 - temperature of the air mixture at the mill drum output, ${}^0C$; t_3- temperature of a cold air at the mill drum input; t_1- temperature of a hot air at the mill drum input, ${}^0C$; F – hot air flow, м^3/g; TC1-control block 1; TC2- control block 2; TC3- control block 3; G - raw coal flow, t/g; m – weight of the raw coal; n - motor speed; PC - pressure regulator; v - information from vibration sensor

Figure4 – Functional diagram of the optimal control system of ball drum mill volumetric loading with stabilization of air mixture temperature and explosion safety control elements

In [4] the diagram of explosion safety of methane-air mixture is presented (fig. 5). From this diagram it follows that almost all mixtures of methane with air are represented by a plane below the line AL. Point B corresponds to the lower concentration limit of methane explosiveness in air (5% methane and 95% air), and point C - the upper (VMV, 15% methane and 85% air). Point D corresponds to the lower concentration limit of explosiveness of the mixture for oxygen GKK (NMV 6% for methane and GKK-12% for oxygen). Points B, C and D form a contour, called the explosive triangle, within which the methane-air mixture is explosive. The BD line is the line of the lower concentration limits of explosiveness, and the CD line is the line of the upper ones. The area to the right of the CD line, which is bounded by the DHMC circuit, is the area of non-explosive mixtures, but which can become explosive at oxygen concentrations above 12%. Based on the analysis of the diagram (Fig. 5) the conclusion was made about the possibility of increasing the resource saving of mine methane with concentrations below 25% by regulating the emission of its production and taking into account the limits of explosion safety, which are determined by the ratio of the simultaneous concentrations of measured oxygen and methane. In this case, part of the mixture of the OABDCLN area is not released into the atmosphere. An explosion-proof polygon OAIKLSO area is formed, which is separated from the explosive triangle BCD. On the right is the LK limit (more than 10% of the line CD), below is the IK limit (5% less than the lower limit of flammability (explosiveness) of oxygen) and on the left is AI limit.



BCD - contour, called the explosive triangle, within which the methane-air mixture is explosive; the DHMC contour – limited area of non-explosive mixtures, but which can become explosive at oxygen concentrations above 12%; BD - the line of the lower concentration limits of explosiveness, CD - the line of the upper ones

Figure 5 – Diagram of explosive methane-air mixture

Based on the analysis of the diagram (Fig. 5), taking into account compliance with the requirements of the "Safety Rules of Coal Mines of Ukraine"[7,8], which regulate the unacceptable volume concentration of methane in a mixture of 3.5- 25%, it was concluded that the value of the oxygen concentration limit should be equal to 7%, that is the doubled normalized value of lower concentration limits of methane explosiveness equal to 3.5%. The upper one should be equal to the normalized value of methane equal to 25%, while simultaneous measuring oxygen and methane concentrations. On this basis, we recommend that the methane-air mixture of the AIKLSO area with parameters below the AIKLS limits be defined as explosion-proof and used in the extraction and utilization of mine methane.

The identified patterns provide a basis for establishing safety criteria for three ranges of methane concentrations in the drum of the mill using equations (1), (2) and (3):

- limit (AI) from 0 to 5% CH_4

$$K_{b1} = \frac{7+|K_{CH_4} - 5|\cdot 2.6 - K_{O_2}}{7+|K_{CH_4} - 5|\cdot 2.6} \cdot 20^{0.5}, \qquad (6)$$

– limit (*IK*) from 5 to 20 % CH_4

$$K_{b2} = \frac{7 - K_{O_2}}{7} \cdot 20^{0.5}, \tag{7}$$

– limit (*KL*) from 20 to 25% CH_4

$$K_{b3} = \frac{20 + |K_{CH_4} - 20| \cdot 1.6 - K_{O_2}}{20 + |K_{CH_4} - 20| \cdot 1.6} \cdot 20^{0.5}, \tag{8}$$

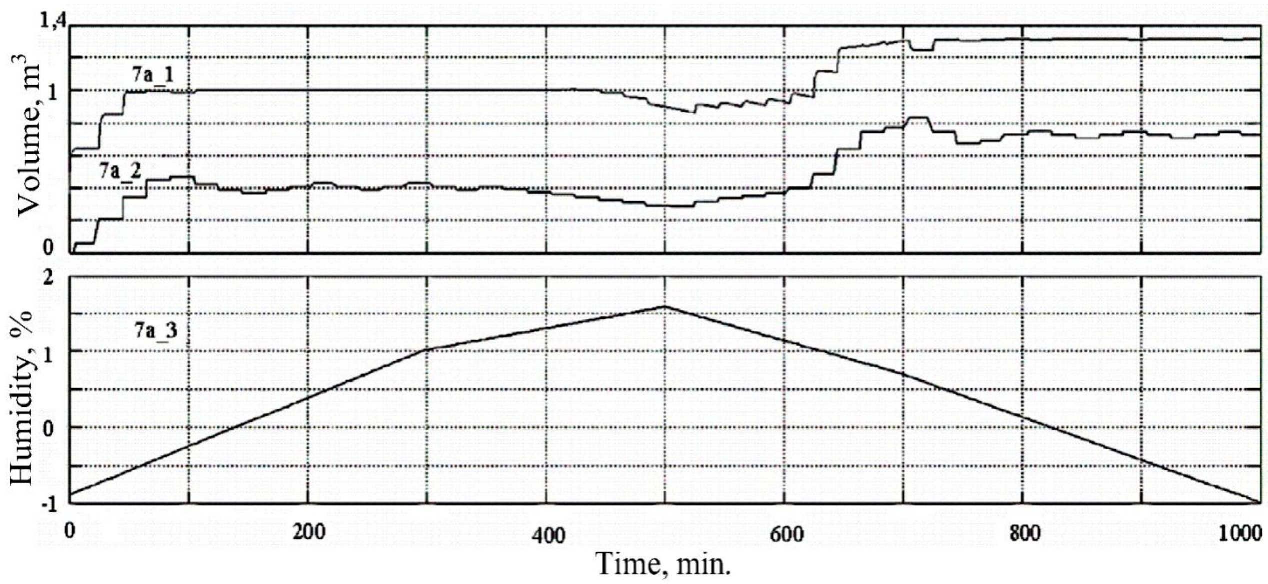
where K_{b1} – the explosion safety factor for the *AI* limit; K_{b2} – explosion safety factor for the *IK* limit; K_{b3} – explosion safety factor for the *KL* limit; K_{CH4} – measured methane concentration, %; K_{O2} – measured oxygen concentration, %.

Equations (6, 7, 8) are obtained by the methods of signature mathematics for solving boundary value problems in information-controlled spaces of technological processes and are used in the formation of control signals of ball drum mill explosion safety.

Based on the functional diagram of Fig. 4 and the above information about explosion safety ensuring in the drum of the ball mill, a block diagram of a mathematical model of the optimal volumetric filling control system with air temperature stabilization and safety elements was prepared [5].

As a result of mathematical modeling of the optimal control system of volumetric filling with stabilization of the air mixture temperature, the following graphical transients are obtained and presented in Figures 6,7.

Fig.7 illustrates the operation of the optimization algorithm, which provides maximum mill productivity with variable properties of raw coal and changes in humidity from 4 to 13%.



7a_1 - productivity of a mill drum, 7a_2 - volumetric loading of a mill, 7a_3 - humidity of coal)

Figure 6 – Transients of optimal control of ball drum mill at variable parameters of raw coal

Figure 7 illustrates the transient processes of temperature stabilization with variable properties of raw coal and also it shows the temperature of the air mixture and the initial temperature value [9,10].

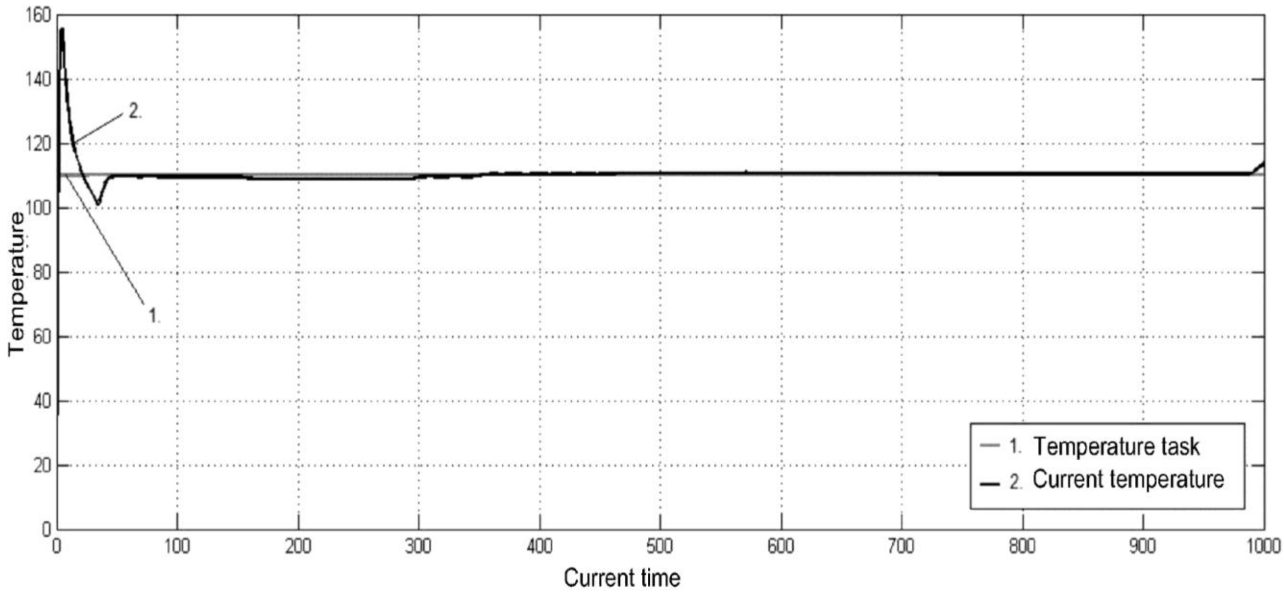


Figure 7 – Transient processes of air mixture temperature control

Results and discussion. To verify the reliability of the developed mathematical models and structural-functional diagrams it was developed system-wide, software and hardware solutions, information support. An experimental-industrial sample of control station "DIYA" was manufactured and put to industrial tests on existing ball drum mills in the Kramatorsk CHP.

As a result, automated control of four 287/410 ball drum mill for feeding steam boilers with pulverized coal mixture, boilers №7 and №9 BKZ-160-100PT was obtained. Based on the information on the vibration acceleration of the bearing support of the mill drum discharge after the mill drum, temperature and concentration of oxygen and methane in the dust-air mixture at the drum output, the automatic control system generates control signals for speed of frequency-controlled asynchronous electric drives, which ensured the steady mill operation at the points of optimum productivity from the level of loading the drum with raw coal and explosion safety. Optimization of ball drum mills for 5500 hours of operation during the year allowed to reduce by 922,900 kWh of electricity consumption for own needs of the enterprise, to reduce specific electricity consumption by (6.99 kWh / t of coal). Due to the stabilization of the grinding tone of raw coal, the power supply of the two boilers decreased by 16,280 tons during the year.

The annual economic effect of the introduction of the automatic control system of SHBM due to the saving of electricity and coal on four SHBM amounted to $ 354,219.

Conclusions.

1. Using the vibration acceleration sensor and the signals processing received from the latter, the volumetric load of the ball mill was calculated.

2. Parameters of explosion safety ensuring of a mill air mixture are established.

3. The system of measurement and calculation of volume loading by coal of a drum of the rotating mill and maintenance of explosion safety of an air mixture of a mill is developed.

4. Mathematical models of grinding processes dynamics of raw coal were developed and research allowed to construct a system of optimal control of volumetric loading of a ball mill with stabilization of temperature of an air mix was carried out.

5. Working design was developed, industrial tests were conducted and station control of ball drum mill was manufactured, implemented and put into operation.

6. The annual economic effect from the implementation of the automatic control system of ball drum mill at the expense of saving electricity and coal amounted to $ 354,219.

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ЗАБЕЗПЕЧЕННЯ ЕНЕРГОРЕСУРСОЗБЕРЕЖЕННЯ ТА ВИБУХОБЕЗПЕКИ ТЕС ПРИ ВИКОРИСТАННІ СТАНЦІЇ КЕРУВАННЯ КУЛЬОВИМИ БАРАБАННИМИ МЛИНАМИ

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Анотація. Україна має приблизно від 300 до 500 кульових барабанних млинів (КБМ), що діють і котрі використовуються в різних промислових сферах. Більшість КБМ на виробництвах працюють не на повну потужність та на старих або слабо модернізованих системах керування. Складність керування КБМ полягає у різних факторах, що впливають на процес подрібнення, а саме: вологість сировини, механічні властивості матеріалу, знос броньових плит та тіл, що подрібнюють. Водночас, вплив цих факторів без високотехнологічних пристроїв ускладнює керування процесу подрібнення, тому на простих системах керування оператори працюють на занижених показниках для стійкої роботи. В роботі розглядаються кульові млини подрібнення сирого вугілля. Проведені експериментальні дослідження режимів роботи КБМ в промислових умовах та на моделях. Запропоновано метод нечіткої адаптації параметрів налаштування регулятора та обрані раціональні алгоритми управління. Результати дослідження системи оптимального керування об’ємним завантаженням КБМ показали високу якість керування при різних зовнішніх впливах. Система керування дозволяє використовувати максимальну продуктивність КБМ. Отримано річний економічний ефект у розмірі 354 219 $ США. Розроблено робочий проект, проведено промислові випробування та виготовлено, впроваджено та введено в експлуатацію станцію керування кульовим барабанним млином. Встановлено параметри вибухобезпечного забезпечення млиноповітряної суміші. Розроблено систему вимірювання та розрахунку об'ємного завантаження вугіллям барабана обертового млина та забезпечення вибухобезпечності повітряної суміші млина.

Ключові слова: енергоресурсозбереження, вибухобезпека, ТЕС, станція керування, кульовий барабанний млин.

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