

Висновки. Таким чином, було підтверджено необхідність врахування запізнювання при ідентифікації математичної моделі. Для статичних багатofакторних об'єктів найбільш доцільно проводити побудову парних взаємодіючих функцій між кожною предикторною та залежною змінними. За допомогою екстремумів кореляційної функції визначається параметр запізнювання статичних об'єктів розподілених у просторі та часі. Застосування даного методу дозволить проводити ідентифікацію запізнювання навіть при сильно зашумлених статистичних даних ($D_C/D_{III} \geq 1$).

Подальші дослідження авторів будуть спрямовані на розробку ефективних алгоритмів реалізації запропонованого способу за допомогою паралельних обчислень.

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AUTOMATION AND OPTIMIZATION OF SOLID MATERIAL GRINDING BY MEANS OF BALL MILLS

Рассмотрена система автоматического регулирования и оптимизации процесса измельчения твердого материала в шаровых барабанных мельницах. Система обеспечивает измерение основных параметров процесса измельчения и его оптимизацию. При применении системы гарантируется безопасная работа мельницы, повышается энергоэффективность процесса измельчения, а также увеличивается производительность мельницы.

Розглянута система автоматичного регулювання та оптимізації процесу розмелювання твердого матеріалу в кульових барабаних млинах. Система забезпечує вимірювання основних параметрів процесу розмелювання і його оптимізацію. При застосуванні системи гарантується безпечна робота млина, підвищується енергоефективність процесу розмелювання, а також збільшується продуктивність млина.

This work deals with the system for automated control and optimization of solid material grinding in ball mills. The system provides measurement of the main parameters of the technological process of grinding and optimization of this process. By applying the system the safe operation of a

ball mill is guaranteed, the energy efficiency of grinding is improved and the grinding capacity of the mill is increased.

Introduction

The grinding of solid materials in ball mills is of great importance for a number of technological processes. The efficient operation of heat power stations (HPS) working on solid fuel (coal) depends on the efficiency of coal grinding in ball mills. In the same way the efficiency of clinker grinding in ball mills makes significant influence on the efficiency of cement plant operation. Grinding mills are big power consumers since grinding process is power-intensive. The electric power consumption for dust preparation at a HPS amounts to about 20 per cent of the total power consumption for own needs or, otherwise, about 2 per cent of the total amount of power produced [1].

The process of solid material grinding in ball mills has been automated poorly, because there were no methods to measure the main parameters of the grinding process, such as quantity of the solid material in a mill, grinding capacity and especially there were no methods to determine the pre-failure condition in which the mill is so much overloaded that it leads to abrupt decrease in its grinding capacity and to blockage. In order to prevent the failure of a mill the operators deliberately decrease the grinding output by feeding less raw material to the mill, which makes the grinding process more power-intensive and less efficient. There were no reliable methods to find the optimal loading of a mill in order to reach the maximum grinding capacity.

Many investigators, however, with a purpose of ball mill automation, have carried out experimental studies and established relations between the main technological parameters of the grinding process and a number of indirect indexes [2]. Based on these studies, various schemes for automation of ball mills have been proposed to regulate the outlet temperature of the air mixture, the differential pressure at the mill drum and the acoustic signal of the mill. But all those systems could not ensure the maximum possible grinding capacity and they did not prevent a possible blockage of the mill.

The aim of the paper

The aim of this paper is to describe the developed system for automated control and optimization of solid material grinding by means of ball mills based on the system applied for automation and optimization of coal grinding.

The main material of the paper

The maximum possible grinding capacity of coal grinding depends on the coal character (grain composition, grindability index, rock concentration, moisture content etc.), on the dust system characteristics (drying, ventilation and grindability) and on the amount of coal fed into the mill, on the coal feeding system and its regime [3]. The experience of using the systems developed earlier has put forward the task to improve them and to create new algorithms for calculation of actual values of the main technological parameters of the grinding process, including a new method to measure the quantity of coal in the mill. Another task was to develop new algorithms in order to optimize mill performance both under standard conditions and under constraints on drying and ventilation of the dust system. It was also necessary to take additional meas-

ures to provide safe operation of the mill and to try out failure situations. In order to fulfill all the above tasks an intellectual controller-optimizer was developed. The ball mill modeling has shown that depending on the coal and dust characteristics the maximum possible grinding capacity of the mill is reached at the level of 80 to 95 per cent of the maximum possible loading of the mill with the material being ground [4].

The maximum grinding capacity in operating conditions is sometimes constrained by dust drying and ventilation. The deficiency of the former may take place due to large moisture content in the material being ground relative to the nominal value or due to a drying agent temperature decrease. Low drying of the dust system is usually characterized by air mixture temperature decrease at the mill outlet below the minimum limit. Deficiency of ventilation may be caused by blockages of the inlet and outlet throats of the ball mill (the differential pressure at the mill drum exceeds the maximum limiting value).

When operating a ball mill it is especially important to avoid the exceeding of the maximum limiting temperature of the air mixture, which can result in an explosion of the dust system. Therefore the controller-optimizer provides a mechanism to prevent overheating of the air mixture. Additionally a sound alarm is provided to give a signal of a pre-failure situation with a possibility to interrupt the supply of a heating agent. In order to safeguard the dust system the precautionary measures are taken by the controller-optimizer to avoid the temperature going out of the specified range and to avoid the exceeding of the maximum limiting value of the differential pressure at the mill drum.

Due to a specially developed algorithm the controller adjusts automatically to the existing dust system, grindability of the mill and to the qualitative characteristics of the material being ground. As these parameters vary the controller adjusts automatically to regulate the material feeding so that the grinding capacity is always maximum.

The structural diagram of the ball mill automation and optimization system at coal grinding is shown in Fig. 1.

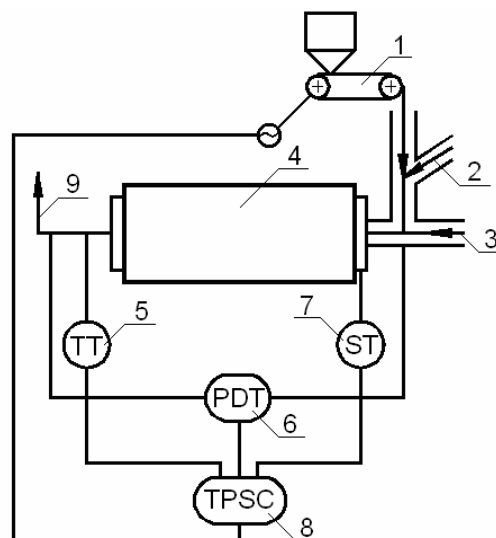


Fig. 1. Structural diagram of the ball mill automation and optimization system at coal grinding:

1 – raw coal feeder; 2 – back from separator; 3 – drying agent; 4 – ball mill; 5 – air mixture temperature transducer; 6 – differential pressure transducer; 7 – transducer of mill charging with material to be ground; 8 – controller-optimizer; 9 – to separator.

The piezoceramic accelerometer is mounted on the front bearing of the mill and it measures the vibration acceleration of the mill bearing which correlates directly with the mill loading with the material to be ground. The interrelation between these parameters is monitored by the controller-optimizer. A temperature transducer is applied to measure the temperature of the air mixture at the mill outlet. A differential pressure transducer is applied to measure the differential pressure at the drum of the mill.

The output signals of all the transducers are 4÷20 mA and they are attached to the appropriate analogue inputs of the controller-optimizer. A control key on the controller-optimizer switches the system to the manual control mode “Distance” or automatic control mode “Automatic”. The coal is fed into the mill by means of a raw coal feeder (RCF) controlled directly by the controller-optimizer. The controlling action of the controller-optimizer is performed by regulating the rotation frequency of the RCF drive (or switching on-off the RCF and changing the position of the RCF knife). The system is equipped with a controlling relay which is switched on by the controller-optimizer when the air mixture temperature exceeds the maximum limiting value in order to stop coal feeding and to ensure dust system safety. It is also equipped with a relay for light signaling of a sharp change (decrease) in the RCF productivity.

The values of air mixture temperature at the mill outlet, differential pressure at the mill drum and relative values of coal loading in the mill are displayed at the front panel of the controller-optimizer. Also the limits of air mixture temperature and the information on the current condition of the controller-optimizer are displayed. The minimum and maximum values of the air mixture temperature and of the differential pressure at the mill drum (T_{min} , T_{max} , ΔP_{min} , ΔP_{max}) are adjusted for each mill type and specific dust preparation system individually.

The main operation mode of the controller-optimizer is to ensure feeding into the mill such a quantity of raw coal at which the maximum possible grinding capacity of the mill is reached. The controller-optimizer switches to other modes when there are constraints on the mill's drying or ventilation, as well as when pre-failure situations occur.

In addition to this, the mill operator's panel is equipped with a signaling system for abrupt decrease in the raw coal feeder productivity (insufficient knife opening, presence of foreign material). This signaling and the signaling for exit of the parameters being measured beyond the feasible limits are on permanently irrespective of the controller-optimizer operation mode. When the system gets beyond the limiting conditions, the controller-optimizer switches to the dynamic optimization mode in search for an optimal coal loading of the mill.

When there are no constraints on the mill's drying and ventilation and when there is no pre-failure situation the controller-optimizer operation mode is determined by the relative degree of mill loading. So when the relative degree of mill loading is less than 40%, the coal is fed into the mill continually at the maximum possible productivity of the RCF. In other cases coal is fed into the mill according to a special algorithm until the maximum value of coal loading degree is reached.

As the optimal value of the mill loading is reached, when the dust system operates at the maximum possible productivity, the controller-optimizer maintains this value as long as the technological process conditions do not change.

The productivity of RCF should be 1.5 - 2 times higher than the mill's grinding capacity. This is the main condition to ensure normal running of the technological process of coal grinding in the mill. When the RCF productivity is insufficient, the controller-optimizer operates in a non-standard mode which is characterized by a lower degree of mill loading. This, in its turn, results in an ineffective operation of the dust system.

Insufficient drying and ventilation of the mill are also limiting factors for reaching the maximum possible grinding capacity of the mill. When such constraints occur, optimization of mill operation is possible within the specified constraints.

The developed automation and optimization system was installed at a number of ball mills at heat power stations for grinding the coal, at cement plants for grinding the clinker and at ceramic plants for grinding the clay. One of the systems was installed at a heat power station with a 300 MW power generating unit where three ball mills were used for coal grinding. Application of the system provided improvement of grinding capacity of the mills in such a way that the capacity of two mills was enough for preparation of the fuel for the power generating unit and the third mill was turned off. This is how energy saving by 30 % at coal grinding was reached.

Conclusions

The developed ball mill control and optimization system provides accomplishment of the following functions:

- Measurement and calculation of the actual values of the three main technological parameters: loading degree of the ball mill with the material being ground, air mixture temperature at the mill outlet and the differential pressure at the mill drum.
- Optimization of the grinding process including continuous search and stabilization of the ball mill loading degree by regulating the feeding into the mill in order to ensure the maximum possible grinding capacity of the mill.
- Continuous monitoring of drying and ventilation of the dust system, and in case of decrease of these parameters down to critical values – optimization of mill operation within allowable constraints.
- Visualization of controller operation modes, current values of the mill loading degree, the air mixture temperature at the mill outlet and the differential pressure at the mill drum, as well as minimum and maximum limits of the air mixture temperature and the differential pressure at the mill drum.
- Signalization of work and stops of RCF, occurrence of constraints on dust system drying and ventilation, exceeding of the maximum limiting temperature value of the air mixture, existence of pre-failure situations.
- Prevention of mill blockage by the material being ground.
- Guarantee of safe operation of the dust system in automatic mode.

Implementation of the system ensures a considerable increase in grinding capacity of a ball mill irrespective of the quality characteristics of the material being

ground and the dust system condition. It also consumes less power per unit weight of the material being ground.

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МОДЕЛЬ СИСТЕМЫ УПРАВЛЕНИЯ ОЧИСТНЫМ КОМПЛЕКСОМ, ОСНОВАННАЯ НА СЕТИ ПЕТРИ

В статье рассматривается возможность применения аппарата сетей Петри при моделировании системы управления оборудованием очистного комплекса, основанная на методе логического синтеза поведенческой модели.

В статті розглянуто можливість застосування апарату сіток Петрі при моделюванні системи управління устаткуванням очисного комплексу, що заснована на методі логічного синтезу поведінкової моделі.

The article discusses the possibility of the use of Petri nets in the modeling of the system of management of equipment of coal-mining complex based on the method of logic synthesis of a behavioral model.

Вступление. Методы реализации сетей Петри можно разбить на два класса: программное обеспечение и аппаратная реализация. Реализация сети Петри в программном обеспечении представляет собой оценку сети с использованием программы на компьютере. Это получило широкое применение при моделировании и представлении проблем оценки.

Возможность реконфигурации во время выполнения позволяет использовать приемлемые алгоритмы, которые позволяют сократить время, необходимое для моделирования сети. Методы аппаратной реализации сетей Петри могут быть разделены на методы прямого преобразования и методы логического синтеза. Методы логического синтеза зачастую зависимы от проблемы использования состояния, потому что большинство современных систем обычно моделируются как параллельные. Методы прямого преобразования могут быть реализованы аппаратно.