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USING OPTICAL SIGNALS FOR PULVERISED COAL COMBUSTION PROCESS OPTIMAL CONTROL TO INCREASE ECONOMIC EFFICIENCY OF THE BOILER

Legal regulations and technological restrictions in energetics sector impose the need for efficient control of pulverized coal combustion's complex process. Process control difficulties are the result of unavailable or incomplete information about the combustion process. The article presents the model of predictive control based algorithm for combustion process control using optical signals (esp. changes in selected parameters of the flame). The authors discuss the correlation between the selected process models and indicators of optical signals used in the control algorithm.

Keywords: *combustion boiler, combustion process, predictive control, diagnosis.*

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ВИКОРИСТАННЯ ОПТИЧНИХ СИГНАЛІВ ДЛЯ КОНТРОЛЮ ПРОЦЕСУ СПАЛЮВАННЯ ПОДРІБНЕНОГО ВУГІЛЛЯ ЯК МЕТОД ПІДВИЩЕННЯ ЕКОНОМІЧНОЇ ЕФЕКТИВНОСТІ РОБОТИ БОЙЛЕРА

У статті показано, що законодавчі умови і технологічні обмеження в енергетичному секторі призводять до необхідності ефективного контролю за процесами спалювання подрібненого вугілля. Контроль цього процесу викликає труднощі через недоступність або неповноту інформації про сам процес спалювання. Представлено алгоритм на основі моделі прогнозованого контролю з використанням оптичних сигналів, особливо змін характеристик полум'я. Представлено кореляцію між моделями процесів і індикаторами оптичних сигналів, використовуваних у контрольному алгоритмі.

Ключові слова: *твердопаливний котел, процес спалювання, попереджувальний контроль, діагностика.*

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ИСПОЛЬЗОВАНИЕ ОПТИЧЕСКИХ СИГНАЛОВ ДЛЯ КОНТРОЛЯ ПРОЦЕССА СЖИГАНИЯ ИЗМЕЛЬЧЕННОГО УГЛЯ КАК МЕТОД ПОВЫШЕНИЯ ЭКОНОМИЧЕСКОЙ ЭФФЕКТИВНОСТИ РАБОТЫ БОЙЛЕРА

В статье показано, что законодательные условия и технологические ограничения в энергетическом секторе приводят к необходимости эффективного контроля процессов сжигания измельченного угля. Контроль этого процесса вызывает трудности из-за недоступности или неполноты информации о самом процессе сжигания. Представлен алгоритм на основе модели прогнозируемого контроля с использованием оптических сигналов, в особенности — изменений характеристик пламени. Представлена корреляция между моделями процессов и индикаторами оптических сигналов, используемых в контрольном алгоритме.

Ключевые слова: *твердотопливный котел, процесс сжигания, упреждающий контроль, диагностика.*

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1. Introduction. The modern notion of efficiency concerns different parameters: technical, economic, as well as ecological — regarding the regulations of the European Commission, especially: the IPPC (Integrated Pollution Prevention and Control), which is reducing emissions of NOx, CO and SO2. The problem is that industrial coal combustion based (facilities) installations have to carry out the combustion process in boilers, which largely date back 50 years. Therefore, energy production based on pulverized coal combustion and biomass coal is focusing on the primary low-emission combustion techniques [3; 4; 6].

Different sources [1-8] indicate that modern measurement, diagnostics and control methods associated with the use of primary low-emission combustion techniques will meet the rigors of the LCP (large combustion plants) Directive. Such approach is ecomically feasible unlike the high costs of catalytic reduction methods potential deployment [4]. Thus low cost reduction of nitrogen oxides (NOx) stands as a very important issue [3, 6].

The difficulties in such a process effective control are the result of the mutual interference of nonlinear, physico-chemical properties, delays in dynamics, some of the measured values unavailability and because of the combustion process unpredictability and loosing stability. In addition, the existing process control restrictions are due to unavailability of specific process signals (inputs or outputs) and therefore, incomplete knowledge about it (the process). Today's fast measuring and computing equipment as well as modern algorithms and technology allow detecting hidden relationships between the elements of such a complex process and use them in control algorithm [1, 8].

2. Combustion research facility. Research related to the pulverized coal combustion and biomass co-combustion process in industrial plants have many difficulties to overcome. It is due to the lack of technical capacity to carry out specific tests (e.g., the requirement of licenses for the installation of measuring equipment related to the interference in the installation) and for security reasons.

Combustion tests were done in a 0.5 MWth (megawatt of thermal) research facility, enabling scaled down (10:1) combustion conditions with swirl burner. Its main part is a combustion chamber of cylindrical shape, 0.7 m in diameter and 2.5 m long. A low-NOx burner about 0.1 m in diameter is mounted horizontally at the front wall. The stand is equipped with all the necessary supply systems: primary and secondary air, coal, and oil. Pulverized coal for combustion is prepared in advance and dumped into the coal feeder bunker. Biomass in a form of straw is mixed with coal after passing through the feeder.

The study included the stabilization of the operating point of the combustion chamber at different strengths, different types of fuel (taking into account the coal and biomass) and 3 types of removable low-emission burners [2; 7; 9; 10].

The combustion chamber has two lateral inspection openings on both sides, which enable image acquisition. A high-speed camera with CMOS area scan sensor was placed near burner's nozzle. Flame images were transferred from the interior of the combustion chamber through a 0.7m borescope. The camera was capable to acquire up to 500 frames per second at its full resolution (1280x1024 pixels). The optical system was cooled with water jacket. Additionally, purging air was used to avoid dustiness of optical elements of the probe.

The registered values included multipoint measurements of the concentration of NO_x, O_2, CO, CO_2 gases, temperatures, pressures and flows as well as air fans control levels.

Using high-speed camera with a borescopethe images sequences of the flame were recorded. Regarding them different image parameters (called descriptors) can be specified and then used for the flame stabilization. It is important both for the combustion process quality and safety.

The initial stage of works included the analysis of selected and recorded input and output values. For the purpose of multi-dimensional model synthesis (MIMO) specified input vectors were determined, regarding the secondary air flow, fuel expense, concentration of NO_x, CO and flue gas temperature in the chamber respectively. All values were recorded in the first measurement point, next to the installed digital camera system borescope. The optical recordings were determined according to the parameters such as surface of the flame area, the X,Y geometric center of the flame coefficients, contour length.

3. Assumptions and the concept of the control algorithm. In the case of complex and difficult processes, such as the combustion process, the potential problem of the control system development is the result of incomplete information about the control plant. It is caused by process nonlinearity, unspecified latency, or the measurements of physico-chemical characteristics of certain areas of the system unavailability. In the proposed solution, the classical system was only supplemented with additional information from the flame image, recorded by a fast digital camera.

The relationship between the parameters describing the variability of the flame and exhaust gas temperature in the chamber, or the amount of air flow in the secondary factor was found as a result of the data analysis. Therefore, since the temperature is the inert nature, low frequency value, the high frequency optical signals (actually pictures based parameters of the image) can be successfully used.

Due to the incomplete knowledge about the control plant or its properties changes the quality of fixed parameters plant seems to be insufficient and frequently require the use of adaptive control. Thus, the necessary knowledge about the control plant is achieved by the identification process. This leads to obtain an object model of a certain structure, for which the controller synthesis is carried out. The use of parametric identification for the real-time parameters adaptation can be performed for a given control law structure.

Optimal control problems can be solved using Bellman's dynamic programming method, solving the optimal feedback, based on Hamilton-Jacobi-Bellman (HJB) equation solution. However, for nonlinear systems it is rather difficult to find a solution to the first order nonlinear partial differential equation. Simpler solution involves solving a periodic optimal control with finite horizon, the currently defined on the basis of measurements, the initial condition. It provides a basis for predictive control [5]. In the control MPC (model predictive control), the controller determines the control law in advance, before the system outputs values change. This is the method of optimal control, with the initial condition equal to the current state of the object of estimation. The initial part of the found solution (control function) is expressed to the plant input. Then, the whole procedure is repeated for the new currently designated state of the control plant [1, 2, 8, 9].

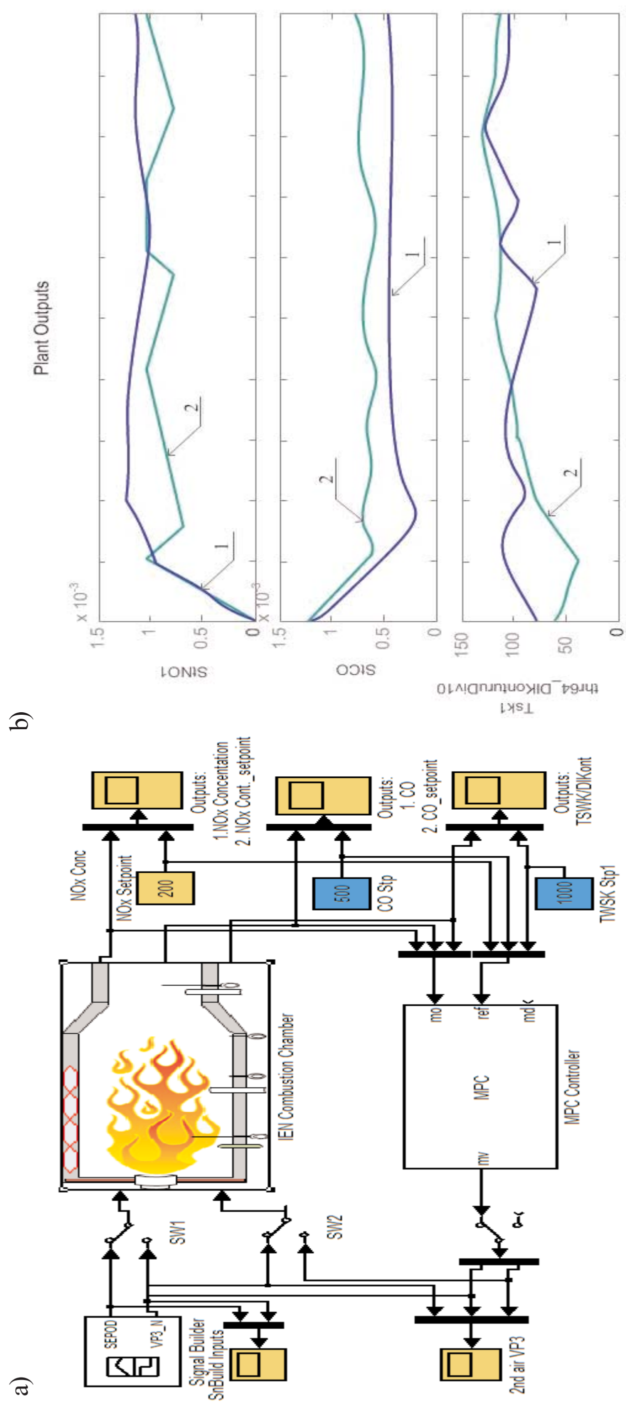

Figure 1. **Combustion control Simulink diagram (a) and NO_X stabilization plots for designed MPC controller both with optical parameter input (1) and temperature (2)**

In order to predict the controlled outputs values a plant model is required. For the research purpose it was developed using the system identification toolbox, based on the measured values of input and output signals of the process. MPC controller rapid prototyping was carried out using MPC Toolbox. Diagram of the control system is shown in Figure 1a.

Then, simulations were made to stabilize the inputs regarding the image and the temperature variation of the controller corresponding parameters. The selected waveforms are illustrated in Figure 1b.

4. Conclusion. The paper proposes a system of model predictive control based optimization algorithm for the pulverized coal combustion and biomass co-combustion process, that also include standards for NO_x, CO and SO_2 radicals emissions. There are two approaches compared: new — using some parameters of the flame image variations and classic — using the physical parameters. The results of simulation studies have confirmed potential possibilities of the flame optical information usage. Nevertheless, the suboptimal nature of the proposed model ought to be emphasized. The MPC algorithm is not sensitive to the model parameters changes, but it depends on the changes in the model structure.

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