One Approach to Combustion Control in Thermal-Power Plant Boilers

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Introduction

Research related to the temperature distribution within the thermal power plant boilers and attempts to use this information for the combustion control process are intensive in the last few decades. In recent years this topic is of great importance considering the high objectives in energy efficiency and environmental protection. This is supported by the fact that many companies are oriented towards the sensor production technology which provides insight into the temperature distribution inside the boilers.

This kind of research has many advantages. Some of them increase the safety and availability of the overall system by decreasing the fault probability, some are dominantly oriented towards reducing the environmental pollution and others are directly related to the optimization of the energy production process and cost reduction.

The common causes of the failure of the tubes in boilers are due to tube temperature higher than expected during the original design. Tube temperature increases slowly over many years or rapidly caused either by loss of internal steam or water flow. Internal oxide scale or deposit formation usually results in long term overheating that gradually increases the temperature [French, D.N.,1993, Rahman and Sukahar, 2008]. The remaining life span of the boiler tubes that are installed in a fossil fueled power station can be predicted if the stress and average temperature of the tubes are known, together with the way the tubing is thinned or scarred as a results of erosion and corrosion processes [Zarrabi et al, 1996]. Therefore, temperature distribution in the boilers needs to be analyzed numerically.

McKenty et al [McKenty et al, 1999] considered different types of boilers and incinerators and simulated temperature distributions in them successfully. The failures of boiler tubes due to fireside corrosion in a waste heat recovery boiler utilizing the exhaust gas of a gas turbine fired with high-speed diesel were analyzed in [Srikanth et al., 2003]. The application of finite element method to analyze the tube temperature distribution in a water tube boiler is presented in [Rahman and Sukahar, 2008]. A simulation of thermal flow in an industrial boiler using a CFD (*Computation Fluid Dynamics*) package was conducted and presented in [Saripally et al. 2005]. Computer simulation has been employed to understand the thermal flow in the boiler, to resolve the operational problem and search for optimal solution. The CFD analysis provided fluid velocity, pressure, temperature, and species concentration throughout the solution domain. An engineering tool by which the combustion behavior of coals in coal-fired utility boilers can be predicted is developed in [Korytnyi et al, 2008]. It was reported that computational fluid dynamic codes can successfully predict performance of full-scale pulverized-coal utility boilers of various types, provided that the model parameters required for the simulation are properly chosen and validated.

On the other hand, oxides of nitrogen (NO_x) are a major pollutant evolving from combustion processes. Emission regulations of many governments became increasingly stringent, in order to abate harmful NO_x emissions. Available literature offers the following NO_x reduction strategies for stationary combustion: combustion modifications, fuel additives and alternative fuels, reburning technologies, low NO_x burners, feedback control and monitoring technologies. Different simulation tools were used for these purposes. Computation Fluid Dynamics (CFD) has been used to simulate combustion for decades. Simulations have been employed to assists in the design of improved burner geometries, the analysis of alternative fuels and reburning conditions, and various other applications.

Many companies have made significant efforts to provide appropriate temperature sensors and cameras in order to make temperature distribution available. The proper instrumentation, control logic, and control system are required to assist the operation personnel in performing safe, efficient, and reliable operation. Process control, performance diagnostics, and condition monitoring are key technologies used to decrease or mitigate uncertainties. These technologies address three conditions: safe and reliable operation established by process control, efficiency optimization facilitated by performance diagnostics and preventing process and component deterioration detected by condition monitoring.

A small number of papers, available in the literature, are dedicated to obtaining control laws which use the estimated temperature distribution in order to make the firing adjustments. This is a very complicated problem whose complexity derives from the fact that the boiler with its subsystems is a highly distributed system with many inputs and outputs. Meanwhile, the non-guaranteed and variable calorific fuel value (when it comes to coal-fired boilers) is a constant source of disturbances. This paper is dedicated to solving such problem. By conducting some carefully prepared experiments and adequate statistical analysis of the obtained results, it is possible to form an experimental model which will be used to formulate the control law.

Following the Introduction which defines the problem and gives a short overview of the relevant available literature, the next section is dedicated to description of the analyzed system and the installed measurement and acquisition support, obtained results and their analysis. Finally come the Conclusion and the list of used literature.

Boiler System Description

Thermal power plant „Nikola Tesla A“ (TENT A) is located in Obrenovac, Serbia and represents the biggest thermal power plant in Serbia. It consists of six blocks with overall power of 1650MW and it was built in phases during the period from 1970 to 1979. All blocks use lignite coal as a regular fuel, with low and variable calorific power in the span from 5000 to 9000kJ/kg. Additionally, auxiliary oil fuel is used for firing boilers and supporting fire with low calorific value coal firing. Coal combustion process produces solid coal products in terms of large amounts of ash and slag, which are then collected and evacuated to the ash and slag dump located near the plant, using an internal and external transport system.

Within the A6 block with nominal capacity of 345MW, there is a distributed control system (DCS) which controls the boiler operation, while the additional SCADA system does the monitoring, supervisory control and storing data related to the system behavior. Such system enables efficient plant control process, as well as different possibilities of performance improvements and block functionality optimization in terms of energy efficiency and environmental protection, by reducing harmful combustion products. This can be achieved by better fire control and uniform temperature distribution inside the furnace.

The considered block has six mills, which are distributed in such a way to form a tangential configuration of the furnace, as shown in Figure 1. Six oil fuel burners are used to support fire during the ignition process and some unexpected situations such as mill outages, coal shortage, full load demands using extremely low calorific value coal, etc. Use of these burners is justified in such situations considering the price of the driving fuel and the possible damage that can lead to fire extinction and significant losses.

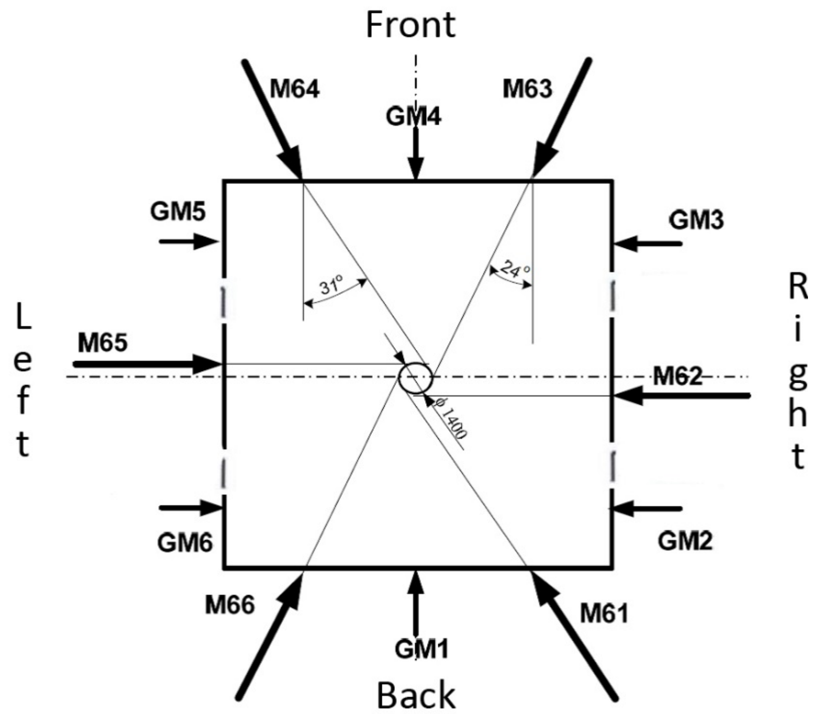


Figure 1. Position of mills and oil fuel burners on the A6 block, forming the tangential structure of the furnace: Mills M61-M66, Oil fuel burners GM1-GM6.

The main task of the control system is to maintain a reference block power, while controlling the fresh steam pressure in front of the turbine. These two technological requirements are achieved by inserting a certain amount of coal and fresh air into the boiler, but also by adjusting the turbine valve openness. In the coordinated operating mode, turbine regulator maintains the preset power. The fresh steam pressure is achieved by coal amount regulation, which is distributed among the mill circles depending on the mill condition, number of operating mills, working regime, and other technological parameters. Since the total amount of coal is divided onto six mills (in nominal working mode), there is a certain degree of freedom in deciding how to load which mill. Therefore, it is possible to affect the spatial distribution of flame inside the boiler, by controlling the distribution of coal per each mill. This additional potential will be investigated in terms of how to redistribute the coal in order to achieve optimal temperature distribution in specific cross section of the boiler.

Pyrometer System Description

Original plant with initial power of 308MW was upgraded to the power of 345MW, during the reconstruction and modernization of TENT A6 block. On that occasion, a new boiler visual supervision system was installed in order to improve the energy efficiency of the block. This kind of system includes the pyrometer system, which was built into the boiler during the reconstruction and modernization phase. The main idea was to exploit the computing and memory capacities of the DCS system which have so far been unused. Namely, the idea was to obtain the information about the furnace condition using the installed pyrometer system and to use them in order to adjust the combustion process control.

Installing the pyrometer measurement units in the specific places of the boiler, as shown in Figure 2, enables estimation of the flame spatial distribution inside the furnace. That way, knowing the flame condition in the furnace allows additional control adjustments in order to achieve optimal temperature distribution in the furnace.

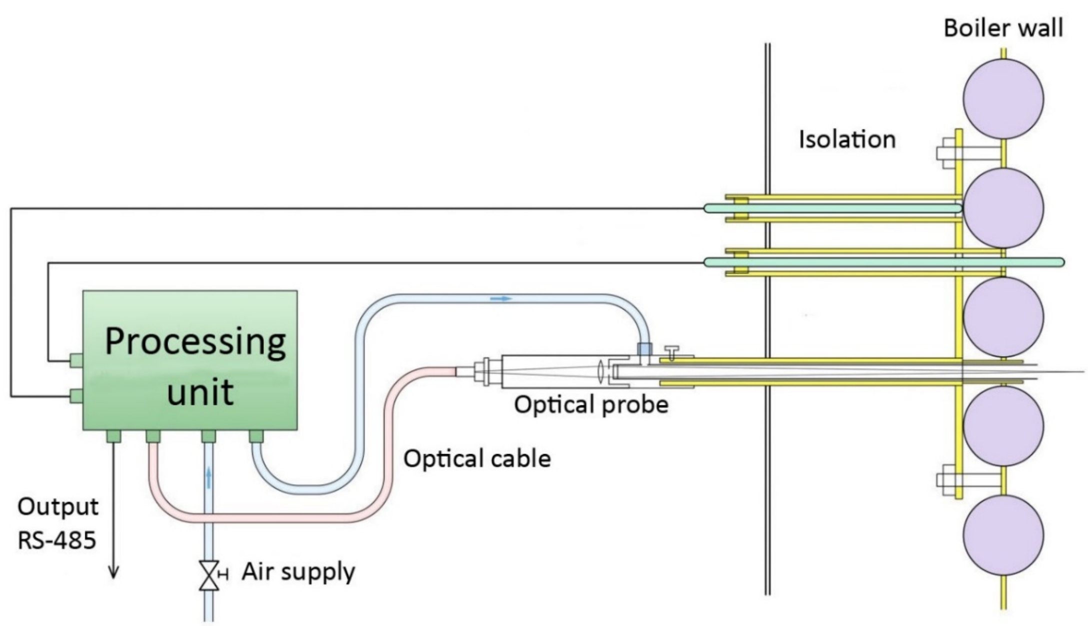


Figure 2. Pyrometer measurement unit with the dedusting and pyrometer cooling system consists of: (1) Pneumatic optical path dedusting system, (2) Optical probe with the air dedusting and lens cleaning connectors, (3) Two-color (two-channel) optoelectronic module, (4) Two-color (two-channel) signal processing units, (4) Box with electromagnetic valves for dedusting.

Two-color processing unit (5) processes the signals obtained from two close wavelength ranges (0,96μm and 1,05μm) and performs the temperature compensation. After that, using the Plank radiation law, it determines the effective mean temperature (the so-called one-color temperature) and approximately the maximum temperature on the optical path (the so-called two-color temperature). Due to measuring method, the value of two-color temperature is under a weak influence of half transparent obstacles in the optical path such as smoke, steam, unburned coal particles, etc. Since the attenuation of the signals on both wavelengths is similar, the obtained temperature is close to the maximum particle combustion temperature. On the other hand, when measuring the one-color temperature, unburned particles, smoke and dust affect the signal. As a result the obtained temperature represents the effective mean temperature on the optical path. Therefore, it can be assumed that the difference between one-color and two-color temperatures represents the measure of combustion efficiency. If the difference is small, the combustion process is more efficient and the mean temperature is closer to the maximum.

Pyrometer system for spatial distribution visualization at block A6, in TENT A, Obrenovac, consists of 42 two-color optical pyrometers which are located at five different boiler levels (at elevations of 17, 25, 38, 43 and 51m), Figure 3.

Pyrometer disposition over the cross sections is dictated by the present condition of the system (obstacles disabling the implementation of the pyrometer system). Figure 4 shows that the optimal pyrometer location for the considered system is: 4 pyrometers at elevations of 17m and 51m, which enable temperature monitoring in the boiler start-up process, and 12 pyrometers per level at elevations of 25m, 38m and 43m, for monitoring the flame focus.

Beside the pyrometer system, visual monitoring is supported by thermographic cameras (DURAG VTA Sistem) with water cooling and pneumatic unit for pulling in and out of the boiler at elevation of 4m and 16m. The first one, at elevation of 4m, monitors the additional combustion process, and the other one provides a termographic display of the lowest elevation zone of oil fuel and air mixture burners. The video signal transfer from the sensor to the processing unit is digital and connection between the two is realized using an optical cable, in order to minimize the electromagnetic influence and maximize the signal quality.

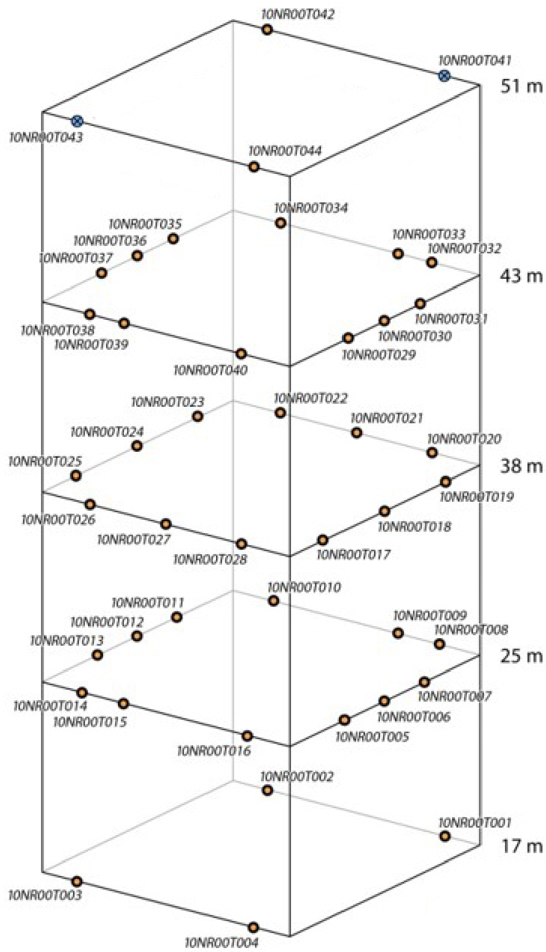


Figure 3. Pyrometer system disposition at TENT A6 boiler (elevation of 17, 25, 38, 43 and 51m)

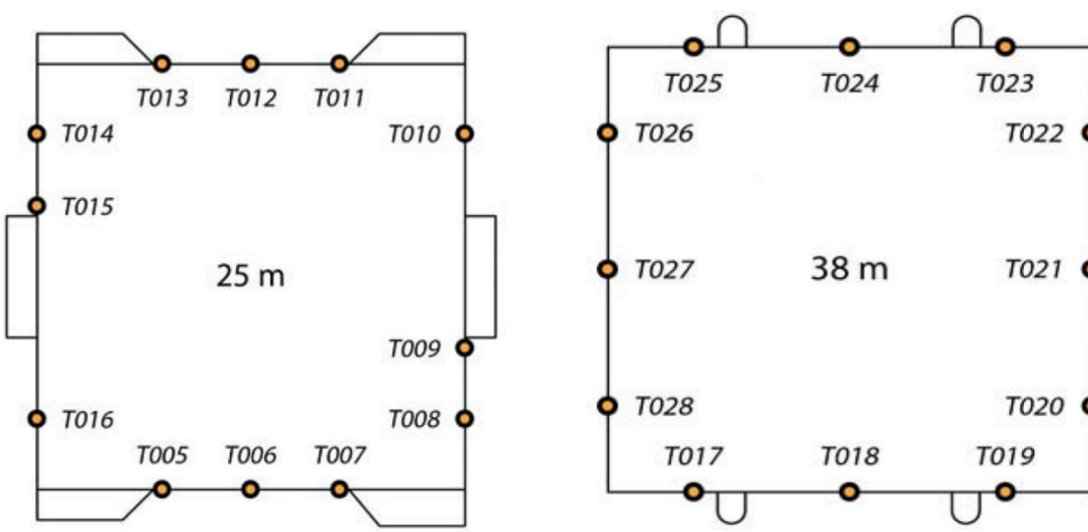


Figure 4. Pyrometers disposition over the cross sections (elevations of 25and 38m) at TENTA6

Experimental Analysis

This research includes experimental verification of the assumption that the change in the separate mill loads, meaning the redistribution of overall load onto the specific mill circles, can influence the spatial flame distribution inside the boiler. Within the DCS system and the main firing regulator operator has the possibility of adjusting mill loads according to their own knowledge and experience. The output control signal of the main firing regulator, meaning the overall amount of fuel, is passed on to the firing distribution process. Depending on the values set by the operators, the redistribution is performed including all mills active in automatic mode. Different experiments were carefully designed for research purposes. They allowed testing of the influence of firing distribution onto the spatial temperature distribution, which can be determined using the pyrometer system installed on the block A6 boiler. Analysis of the temperature within one cross section gives an insight into the flame position within that section. Practice dictates the central position of the flame in order to avoid the non-uniform load of the pipe system, flame and combustion asymmetry, etc.

Experiment was performed in several phases and it involved the analysis of control signal influence onto the temperatures of interest, as well as their interdependence. All tests were done and stored under the regular conditions with nominal load of 348 MW. The same conditions will be later on used for implementation of obtained results. Persistent reference signal is used for the identification of individual influences and input-output dependences, in order to obtain meaningful results. Therefore, the following experiments were performed:

1. Single load change of one mill, while the other mills were in the automatic fuel distribution mode;
2. Single load change of two opposite mills (M61 and M64), increasing the load of one and decreasing the load of other mill, while the other mills were in the automatic fuel distribution mode;
3. Five out of six mills were transferred to the manual operating mode, and the overall fuel change was assigned to only one mill. That ensured a persistent input, because of the fact that the firing control signal is a dynamical quantity under the constant influence of disturbances. As such it can take values from a full range in a very short time period;
4. Four out of six mills were transferred to the manual operating mode, and the overall fuel change was assigned to two mills working in automatic operating mode. During this

mode, the redistribution of load between these two mills was performed in order to monitor the influence of this kind of redistribution onto the furnace flame position.

Experiments three and four are partially shown in Figure 5. All temperature values at elevations of 25m and 38m were logged, as illustrated in Figure 6. Figure 5 shows that some of the mills were in manual operating mode for a long time period (i.e. mills M62 and M63), which is manifested by straight lines coming from the constant load.

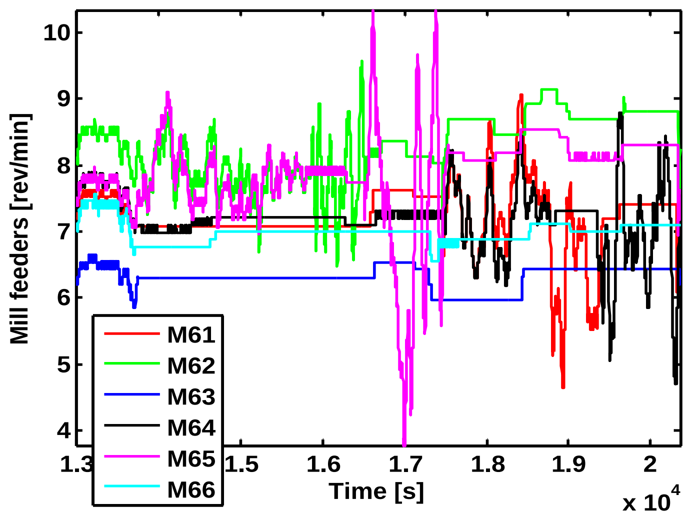


Figure 5. Monitoring temperature distribution as a function of mill circles firing distribution. Figure shows time dependence of the mill loads.

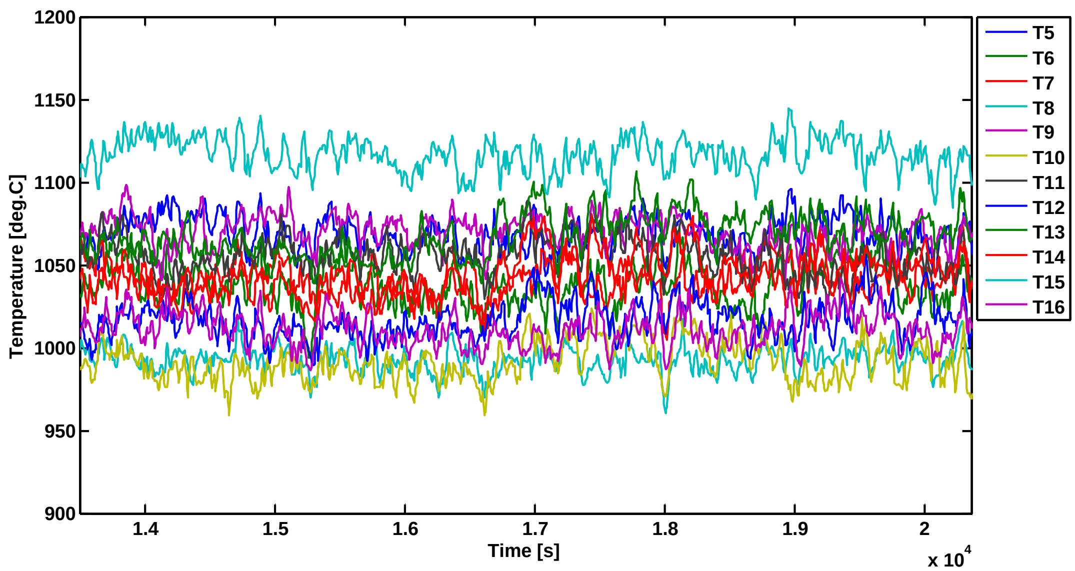
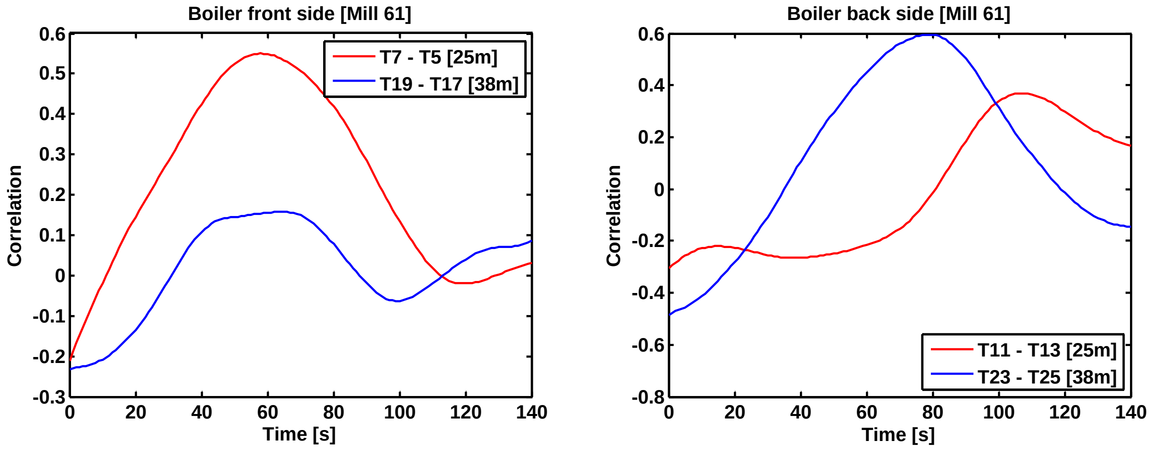


Figure 6. Pyrometer system temperature measurement at the elevation of 25m, three temperatures characterize each off the boiler walls (T5-T7 front, T8-T10 right side, T11-T13 back, TT14-T16 left side)

Described multivariate system is very complex and therefore determining the model of the system is a very complicated procedure. In order to propose the adequate control law, the authors decided to use the cross-correlation functions as a tool for description of systems behavior. Namely, cross-correlation function is a measure of similarity between two signals, and as such represents one of the possible ways of system identification. Considering the cross-correlation functions of individual input-output pairs, it is possible to determine which input affects which output, and how. The unbiased estimation of the cross-correlation function between input signal



(a) (b)

Figure 7 Correlation function between the M61 mill load and temperature differences at different altitudes (25m elevation – red line, 38m elevation– blue line), (a) Front side (b) rear side of the boiler

On the other side, this analysis also confirms that the sixth mill shifts the flame center to the right area of the boiler, since the presented difference is calculated as the difference of the temperatures measured at the right and left side of the boiler. These results confirmed our assumption about the influence of sixth mill charge to the temperature distribution. Adequate results may be obtained for other mills. Figure 8 presents results that are obtained during the experiments that aimed to establish the backward-forward shift of flame center because of fourth and sixth mill load change. The obtained correlation is positive for the sixth mill and negative for the mill number four. This result offers a possibility to control the flame center position making a proper distribution of these mills load.

Figure 9 presents the influence of simultaneous load/relief of the mills one and four to the temperature distribution in the rear area of the boiler. During this experiment these mill were in the closed loop and only their mutual relative participation in the total boiler load was changed. Figure 9(a) shows that the flame centers shifts to the rear while the first mill is loaded and the forth is relieved, while figure 9(b) shows the flame center shift to the left area of boiler.

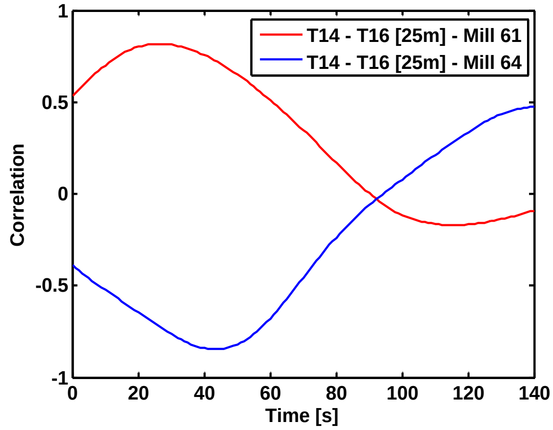
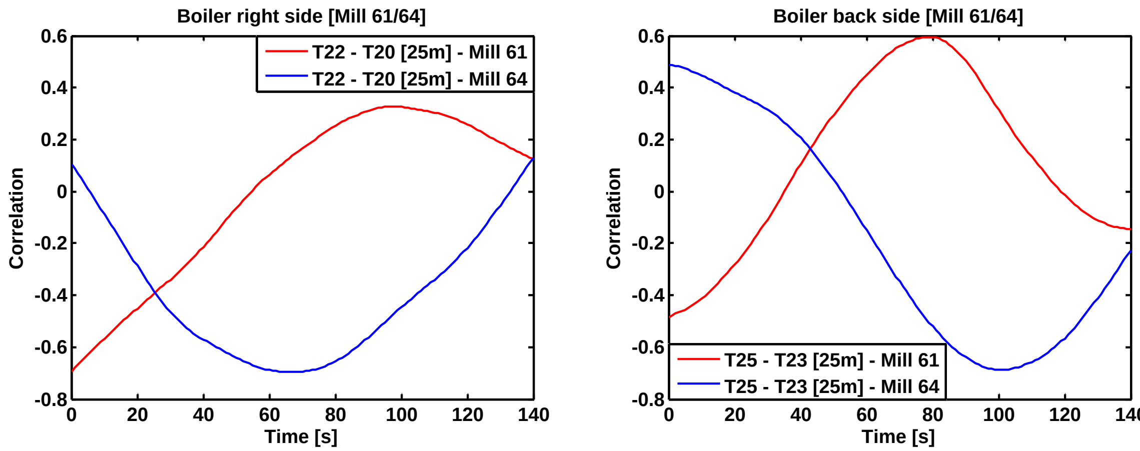


Figure 8 Correlation function between the fourth and sixth mill load and temperature differences at 25m elevation



(a) *(b)*

Figure 9 The influence of the simultaneous load/relief of the mills one and four to the temperature difference in the (a) right area of the boiler; b) rear area of the boiler.

Conclusion

Combustion process monitoring and control is a very important and complex procedure. It ensures quality steam parameter control, decreases environmental pollution by reducing emission of harmful substances, increases energy efficiency and boiler operation safety by avoiding pressure and temperature oscillations inside the furnace, and at the same time it overcomes the problems caused by excessive fouling and slagging of heating surfaces. This kind of combustion process control demands certain theoretical results as a basis for application of different control laws. Standard identification and control procedures are not convenient since the considered system is a highly distributed multivariate process with permanent disturbances. Therefore, paper proposes using cross-correlation functions in order to obtain systems behavior. Experimental results show correlation between certain inputs and certain outputs, which can be used for defining control adjustments in order to obtain desired flame distribution. Namely, the obtained results provide information about decreasing or increasing participation of certain mills in order to move the flame focus to the center of the furnace.

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