W. Wójcik
Lublin University of Technology,
Departament of Electronics, Poland

COMBUSTION DIAGNOSIS USING OPTICAL METHODS

Описано різноманітні конструкції пристроїв моніторингу горіння, які використовують властивості полум'я, і розроблені для застосування під час спалювання пульверизованого вугілля. Наведено одноканальні та багатоканальні рішення. Розглядаються перспективи застосування техніки оброблення зображень.

The paper presents various constructions of combustion monitoring devices, that utilizes properties of flame radiation and are designed for pulverized coal flames. Both single-channel and multichannel solutions has been presented. Additionally, perspective of using image processing techniques was also discussed.

1. Introduction

Nowadays, one of the most important sources of energy is a combustion process of fossil fuels. Growing environment pollution and a perspective of exhaust of commonly used fuels such as coal and oil has led to dissemination of new combustion techniques. A low-emission combustion of coal is one of the most important.

Taking combustion process into consideration, one should not omit a kinetics of the reaction, phenomena connected with transport of heat both in micro- and macro scale. It means, that phenomena of phase transitions, diffusion, conductivity, radiation, dynamics of continuous media ought to be simultaneously considered.

Optimization of combustion process, that takes into account minimalization of the emission of harmful substances, requires information about this process. Even simplified analysis of combustion is a very complicated task, especially in the case of pulverized coal combustion.

The burning of single carbon char particle is a very complex process. First it exchanges heat with the surrounding gaseous medium and the walls of the combustion chamber. It results in particle temperature increase, humidity evaporation and finally in liberation of combustible volatile parts which burn, reacting with the surrounding oxygen. During these processes or after termination of some of them, the remaining coked carbon is being burned. Combustion of the coked part is a result of the diffusion of oxygen, its reaction with the carbon particle and secondary reactions of combustion products on their surface or neighborhood [1]. Already on the basis of the above description one can conclude that the simultaneous analysis of all phenomena involved in the combustion process is impossible.

If a combustion process is accompanied with a flame it is a straight and undelayed source of information. Assessment of combustion quality based on optical methods utilizes information contained within radiation emitted by the flame. In practice, it is sufficient that a deflection from an optimal state can be detected, for it enables entering the proper correction or detecting malfunctions, such as flameout.

2. Flame monitoring systems overview

Generally, flame monitoring systems consist of the following elements [2], [3], [4], [5]:

- measuring probe,
- optical fiber bundle (optional),
- photodetector (or photodetectors),
- signals processing unit.

A schematic diagram of a typical flame monitoring system is presented in Fig.1.

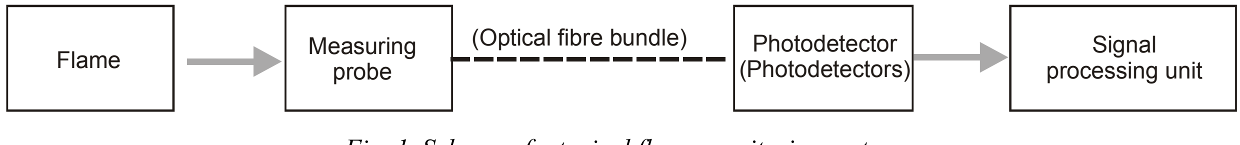

Fig. 1. Scheme of a typical flame monitoring system

The measuring probe

The measuring probe is placed inside a combustion chamber, close to burner and is exposed to temperatures of the order of hundreds degrees centigrade, high dustiness and vibrations [2]. Its construction should ensure a long-term work in mentioned above conditions, delivering the optical signal to the photodetector of the highest possible amplitude level. Dustiness greatly impacts on the signals amplitude, so the proper construction of measuring probe's end should be applied. Optical coupling between flame, that is a volumetric source of light, and the probe should be also taken into account [6].

The solid angle from that the emitted radiation by a flame reaches to photodetector is determined by the place of mounting the measuring probe and its numerical aperture. Single-channel (by Durag, Fireye) [3], [4], or multichannel measuring probes (made in Dept. of Electronics, Lublin Univ. of Technology) are applied [2]. A photograph of multichannel measuring probe is shown on Fig.2

Fig. 2. Multichannel, measuring probe intended for use inside a combustion chamber

A single-channel measuring probes is typically equipped with an optical system of relatively wide acceptance angle and a single photodetector. Multichannel probes ensures selective and independent detection of radiation at a few flame zones with acceptance angle considerably lesser than single-channel versions. A choice of the most sensitive zone to changing a state of combustion process is possible. It enables easier detecting of diversion from an optimal combustion [2].

Optical fiber bundle

In many applications, as for instance in the one proposed by Dept. of Electronics Lublin University of Technology [2], or elaborated by BFI Automation, Durag, Fireye, [3], [4], [5], optical fibers are used, that enables placing of signal processing unit far from high temperatures, vibrations and dustiness. Moreover, it makes mounting of the whole system more flexible.

For the length of the fibers is of the order of a few meters, the attenuation of the optical signal within a spectral range of radiation emitted by a coal flame is negligible. To maximize the radiation power acquired by measuring probe a thick-core PCS fibers was used or HCS fibers for their maximum temperature reaching 350 °C. A typical spectral attenuation characteristic of a PCS fiber is presented on Fig.3.

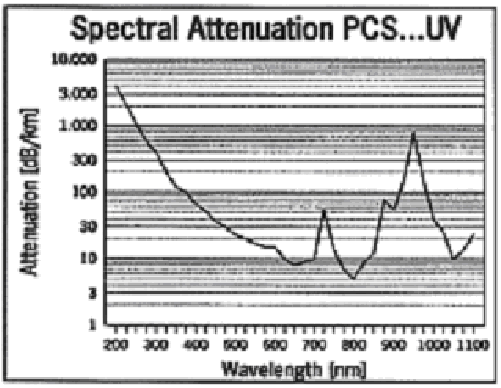

Fig. 3. Spectral characteristic of a typical PCS fiber

For the instances, when a single photodetector is used, a bundle of optical fibers is used instead of a single fiber to increase reliability of a flame scanner [3]. Utilizing optical fibers is not used in all constructions, as it does in the case of BFI Automation scanners, series 8.XX [4].

Photodetector

A photodetector is usually placed beyond the measuring probe, then a flame monitoring system is equipped with a fiber optic bundle. The choice of photodetector depends on the kind of fuel to be burned. It is common to use semiconductor photodetectors, however within the wavelength range from 190 □m 270 □m, a photoelectric cells are used.

For the detection of carbon flames, the most suitable are photodetectors designed for visible or near-infrared range. Materials such as Si, Ge, InGaAs or so called the modified silicon are used. The last one has better performance in the UV range, so it may be applied for mazout flame detection. A typical spectral characteristic of a modified silicon is presented on Fig.4

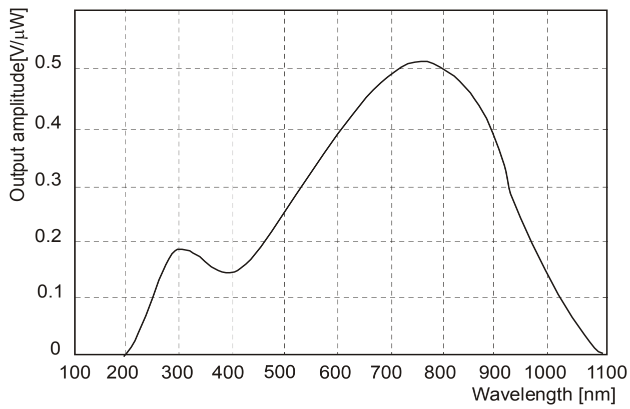

Fig. 4. A typical spectral response for a photodetector made of the modified silicon

To minimize an influence of outer radio noise in industrial conditions and to simplify construction of an electronic part of the whole device, it is better to apply a photodetector with an integrated operational amplifier.

Signal processing unit

In the signal processing unit, a signal obtained from the photodetector is amplified, usually at an adjustable level [3], [7]. Flame monitoring system should be insensitive to interferences of both the adjacent flames and heated up elements of the boiler. For the outer velocities of air-fuel mixture are relatively high, and a burner is equipped with swirling blades, the flame is turbulent. Signal processing unit contains a set of band-pass digital filters, that enables separation a variable component of photodetector output signal within frequency range from about 1Hz to 200Hz. [7].

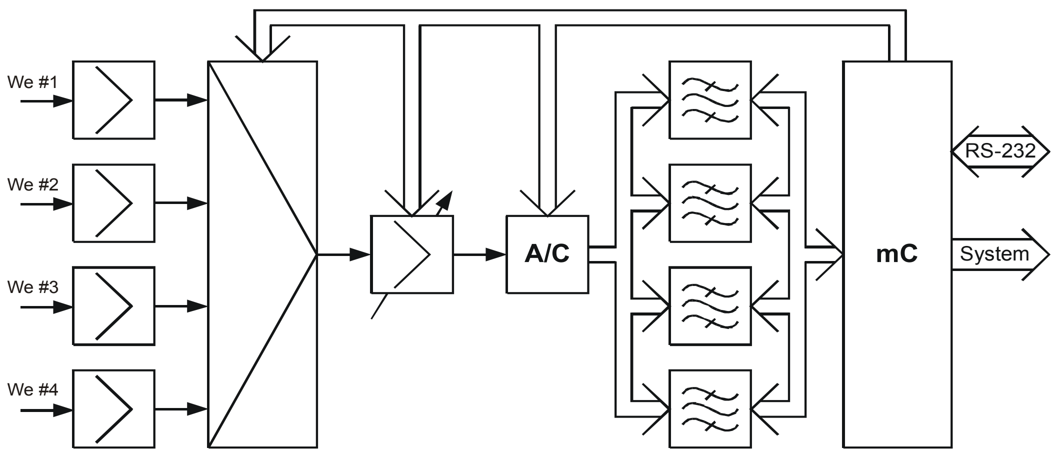

Fig. 5. Scheme of signal processing unit

A functional diagram of signal processing unit, elaborated at Department of Electronics, Lublin University of Technology is presented on Fig.5 [7]. Output signals from the photodetector enter an analogue multiplexer, that selects a channel that is to be processed at that moment. In further part of the signal line a differential amplifier is utilized with an adjustable level of amplification. The amplified signal is converted to a digital form. Next it is filtered with the digital filter of finite impulse response. Signals are then averaged within a time window adjustable from 0,01s to 1s.The main microcontroller of the unit except data acquisition and its averaging, also synchronizes the work of the whole data processing unit, also determining sampling rate of the analogue signals, and setting the channel to be processed and its magnitude of amplification (amplification in each channel can be set individually). The microcontroller decides, to which filter should a sample data from A/C converter be redirected and initiates data transmission from each digital filter.

A separate part of the main microcontroller are configuration function and supervising correctness of work of the whole system.

It is possible to change amplification level, individually for each analogue and also digital signals, spectral characteristics of the digital filters and averaging time of a given signal.

The output are current signals of 4÷20mA industrial standard.

3. Application of image processing for combustion diagnostics

Extension of multichannel measuring probe is use of fiberoscope instead of fiber bundle and a CCD camera instead of a photodiode. Such a solution is equivalent to a multichannel flame monitoring system with number of channels equal to number of pixels in a CCD device.

Application of flame image for accessing combustion process could be done through analysis of flame shape, radiation intensity distribution, and color of the flame image.

In the simplest example, a shape of a binary image is analyzed. A vector of flame attributes is created, that is a set of flame parameters, as lengths of flame image projections on the orthogonal directions, coordinates of its center of gravity, length of the image edge and the like. A state of combustion is characterized through the vector of flame attributes [9].

More sophisticated analysis of radiation intensity distribution uses flame images with 8-bit or 10-bit gray scale (256 or 1024 gray levels, respectively). An analysis of color images consist of its decomposition on component colors (red green and blue) and further proceeding as it does in the case of gray images.

For the great computational complexity of image processing they are narrowed to laboratory tests [10], yet there are no commercially applied.

4. Conclusions

To be based on review of optical flame monitoring systems the following conclusions can be drawn:

– the systems allows monitoring and analysis of the flame in selected zones, preliminary tests in real conditions are required to set up both the probe's mounting and all settings of signal processing unit

– systems for combustion diagnosis permits the analysis of coal-dust flames and also gas and fuel-oil. The proper photodetector should be used, as well as the setting of the signal processing unit.

– they allows monitoring of wall and tangential industrial burners.

– the system allows signal processing, optional selection of pulsation measure as well as selection of the way of presentation of results.

Further development of the systems will be oriented on redesigning of the probe in order to simplify its construction, better protection from hot particles and dust, as well as rising the allowed operation temperature to about 700°C (a special optical fibers is needed).

Unstable combustion of pulverized fuels can be easily detected using image processing [9]. Simple image parameters as placement of image centroid, image mean and variance generally do not require high processor capacity. These measures could be helpful in combustion assessment of coals.

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K. Gromaszek, W. Wójcik, A. Kotyra
Lublin University of Technology,
Departament of Electronics, Poland

STEADY STATE OPTIMIZATION ALGORITHM FOR INDUSTRIAL PROCESS CONTROL

Наведено новий алгоритм “прив’язки до сітки”, який встановлює верхній шар ієрархічної керуючої системи. Цей алгоритм використовується для вибору реперних точок робочої оптимізації. Подано деякі особливості системи і розглянуто основні досягнення оптимізації стабільного стану.

The paper presents a new algorithm Snap To Grid (STG) that constitutes the top layer of hierarchical control system. This algorithm was used for beet-slicers points of work optimization.

Some features of the system were presented and general steady-state optimization approach was discussed.

1. Introduction

The process industry is experiencing important changes due to quality requirements of the high quality, cheap final product as well as decreasing prices of hardware and implementation of optimization techniques feasible from a financial perspective.

Optimization benefits the operation of industrial processes in terms of reduced operating costs and maximized product quality in response to differing feed, market and environmental conditions. The economic optimization of the operating conditions of a process involves the design of an economic objective, which should quantify the factors known to have an economic impact in the way the plant operates. These factors include, for instance, process yield, energy efficiency, costs of energy and raw materials, product prices, etc. The economic objective, together with the process steady state relations, constraints associated with physical limits, safety, environmental regulations, etc. define the optimal operating conditions of the process. For a continuous flow process, these optimal operating conditions usually refer to a steady state operating point, called the steady state optimum. Steady state optimization techniques have also been called optimizing control. For batch processes, the optimal operating conditions refer to dynamic trajectories. In steady state optimization, it is often the case that the optimum operating