Application of wavelet transformation in analysis of signals obtained from optoelectronic device

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Abstract

The paper discusses problems, which arise during monitoring of combustion process in the industrial power boilers. The light-guide device for flame monitoring in industrial conditions is described. Wavelet transformation was used for signal analysis. The sensitivity of Daubechies and Coiflet wavelets to changes of a flame pulsation signal has been tested.

Keywords: flame, light-guide, wavelet transformation, sensitivity.

Introduction

Introduction of new standards for the emission of toxic substances in industrial combustion, according to European Union standards, made power industry to apply the proper factors, which would allow avoiding high penalty for the toxic emission excess. In the Polish power engineering the majority of power stations turn to low-emission combustion [1]. The essence of such kind of combustion lies in the proper distribution of oxygen in power boiler. Therefore, the zone of non-stoichiometric combustion with insufficient amount of oxygen and zone with excess of oxygen is formed inside the boiler. In the first one (with insufficient amount of oxygen), combustion temperature is reduced and it results in increasing amount of both of thermal nitrogen oxides (NO_x) and carbon oxide (CO) [2]. The next flame zone is the one with reduced amount of nitrogen so NO_x formed in the previous zone and resultant concentration of NO_x falls down. In the last zone, the excess carbon monoxide is burned to carbon dioxide. The excess of oxygen in this zone is relatively high, which makes oxygen concentration in flue gases near 5% [2]. A flame monitoring is strongly recommended for low emission combustion, where additional air streams, quantity of fuels (pulverized coal and mazout) are controlled. There is no appropriate mathematical model for combustion in industrial conditions, which would take into account physical and chemical phenomena, especially in the case of pulverized coal [2]. The complexity of the combustion of a single coal grain, even taking simplified assumption that it forms an ideal sphere, and has a uniform chemical composition, do not allow to obtain mathematical model both suitable for controlling combustion in power boiler and for monitoring its quality.

During last 10 years the author carried out works, in order led to choose the factors with the highest sensitivity to input signal changes. These factors can work as output signals of a flame monitoring device. For this application, a special apparatus was designed which consists of a light-guide sensors and microprocessor unit that works in a real-time (Fig.1).

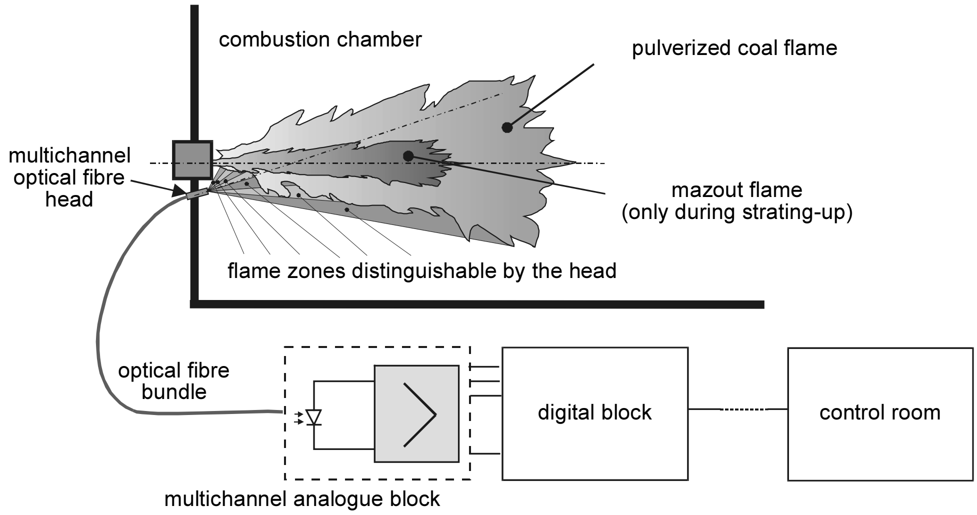

Fig.1 Diagram of flame monitoring device used in industrial conditions.

The application of quartz light-guides with core diameter of 200 μm and of small angular aperture (≈6°), allow to measure signals which are proportional to average flame surface temperature and pulsation. Signal level depends on light-guide angular aperture, flame zone is to be monitored, kind of fuel (i.e. pulverized coal, mazout together with pulverized coal) and boiler characteristics (type of installed burners, boiler capacity, type of combustion chamber). Moreover signals which allow to estimate combustion process quality [3,4] are obtained for the specific boiler. To obtain specific information, signal from light-guide device is processed.

The origin of our investigation comes from serious practical problems, since the staff should exaclty know if burning mazout (at every burner) ignites pulverized coal (explosion hazard). It is very difficult to distinguish signal from the single flame zone corresponding to different type of fuel without any filtering [5]. On the other side, indicators passed only on amplitude, seem to be unacceptable because of variable chemical and physical properties of the fuels. Since the process of combustion, especially in industrial conditions and thus the representing signals are unsteady itself [3], we used wavelet analysis for their testing.

The aim of experiments was to investigate the coupling between a chosen wavelet (its type and order) with signals corresponding to different types of fuels.

Experimental procedure and results

The example signals being analyzed are the output signals of analogue block of the flame monitoring device (Fig. 1) and correspond to the flame flickering from an individual burner. They are recording from the situation when pulverized coal is ignited by mazout. The signals are taken from the channel corresponding to the flame zone, which is mostly sensitive to fuel changes. The discrete wavelet transformation was used in the analysis. The studies were carried out by means of Daubechies wavelets of variable order. The sensibility of wavelet transformation to the signal changes was estimated. The studies were carried out by the subsequent way:

– direct component was excluded from the original signal;
– then, the segments of 0.5min were taken from the beginning and from the end of the sample signal;
– the value of RMS (root mean square to the deviation) was calculated for each segment;
– then, the wavelet transformation was calculated for every segment;

– only one decomposition level was selected by means of filtering and the corresponding to it wavelet indexes, the other levels were normalized to zero;
– for non-zero level the inverted wavelet transformation was calculated, and then RMS was calculated;
– same procedure was carried out over the other decomposition levels.

To be based on the RMS values, obtained by such way, the degrees of wavelet transformation sensibility to signal changes were fixed:

– a quotient of RMS value is computed, corresponding to the beginning part and to the ending one (of the same length) of signal under consideration;

– in order to introduce a measure of variability for filtered signal level, a quotient of RMS value corresponding to the beginning part and the one of filtered signal are is computed – A ;

– in order to introduce a measure of variability for original signal level, a quotient of RMS value corresponding to the beginning part and the one original signal are is computed – B;

– in order to express the quality of filtering quantitatively, the ratio of A and B is calculated (C = B/A), and additionally D = C–1. Then, if D=0, the wavelet transformation based on filtering does not enhance distinguishing among the two parts of the analyzed signal.

Additionally, the studies of wavelet transformation sensibility to the differentiated signal were carried out. The selected results are shown on the Fig. 2–8. On the base of results presented on the Fig.2,4 we have analysed influence of the type and order of transformation on the sencitivity of the system (wavelets coefficients are shown on the Fig.3,5).

As we can see from the fig.3,4, the influence of the signal differentiation on its wavelet transform is essential. This causes the shift of distribution to higher levels. It can be seen from the fig.6,7, that the wavelet series growth causes the distribution shift to a lower levels direction. Moreover, it should be noted, that the difference in the standard deviations is maximum at the extreme levels (fig.8).

The similar calculations were carried out for Coiflet wavelet. To be based on further signal analysis, Coiflet wavelet gives similar results, and for the signal being under consideration, Daubechies wavelet is more applicable. It is connected with the fact that the Coiflet wavelet has only even orders, and the Daubechies wavelets have both even and odd ones. It allows to realize the more precise approximation of the studied signal.

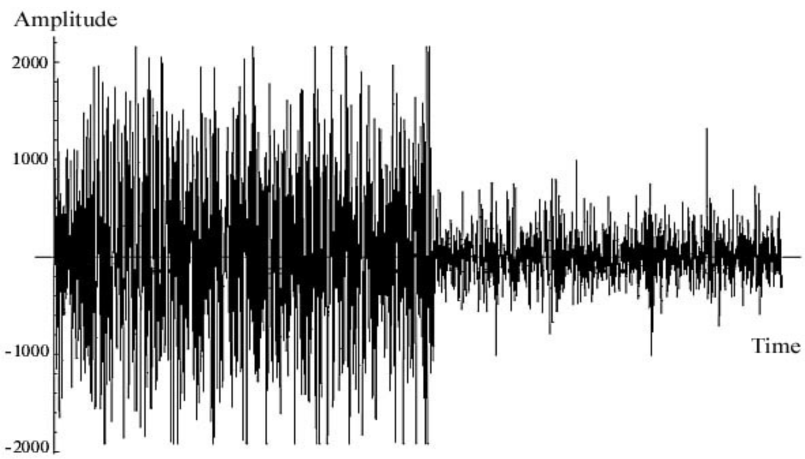

Fig.2. Time performance of the signal after wavelet transform. Duration of the wavelet is 2.5min at frequency of 1 kHz.

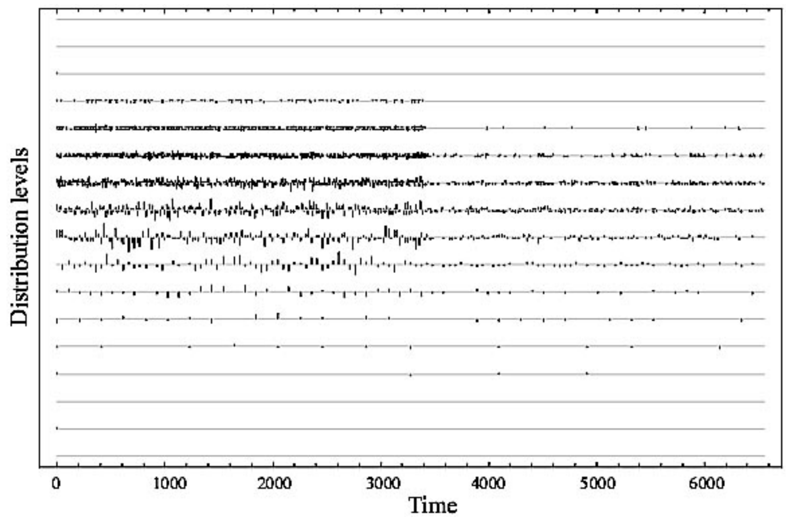

Fig.3. Wavelet coefficients at the corresponding levels of the signal distribution using Daubechies filter of second order.

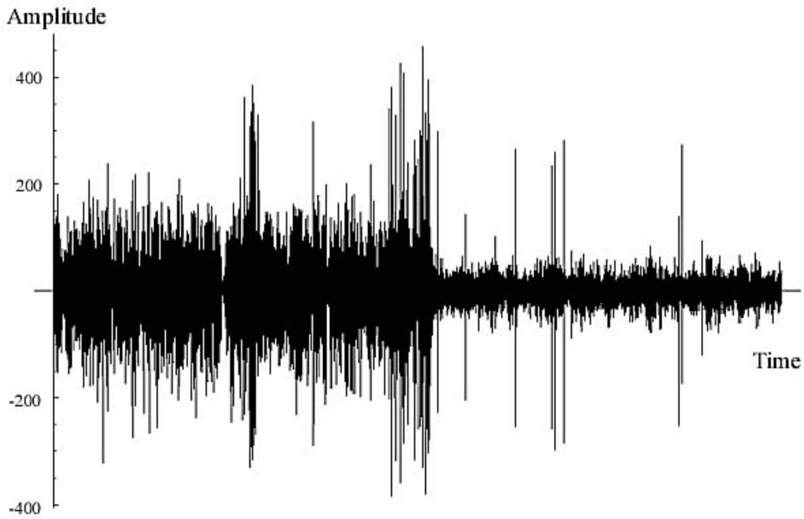

Fig.4. Time performance of the signal after the signal differentiation.

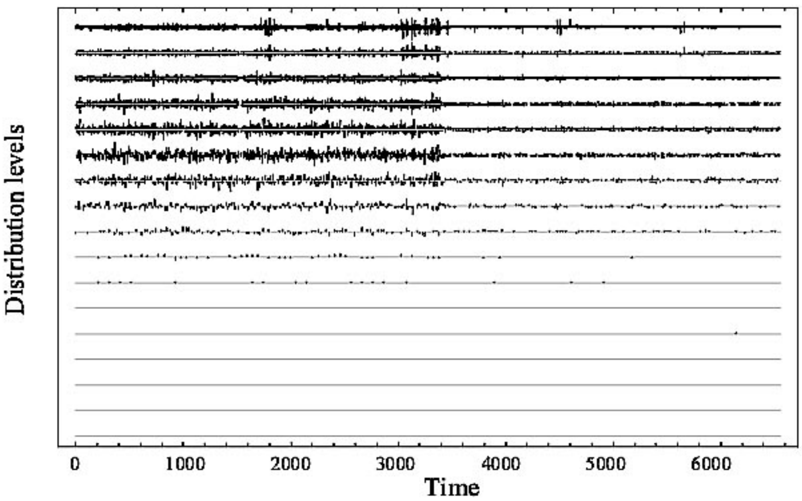

Fig.5. Wavelet indexes at the corresponding levels after using second order Daubechies filter after the signal differentiation.

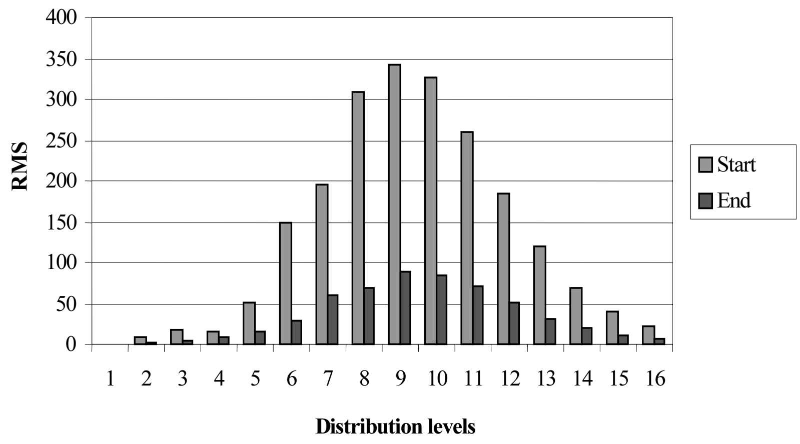

Fig.6. RMS value at the corresponding levels of distribution at the beginning and at the end of the signal by using Daubechies second order filter.

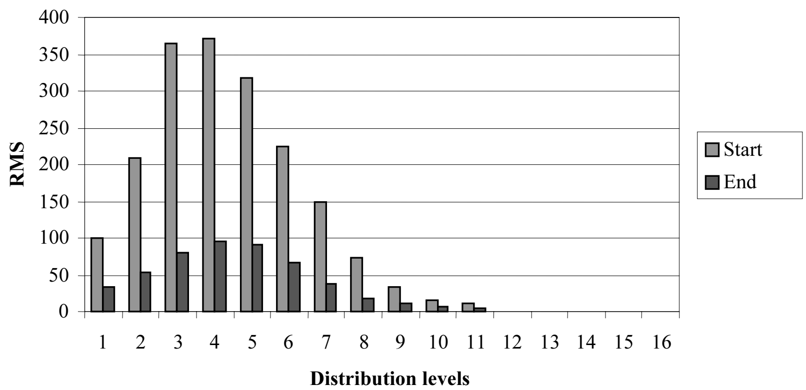

Fig.7. RMS value at the corresponding levels of distribution at the beginning and at the end of the signal by using Daubechies filter of twentieth order.

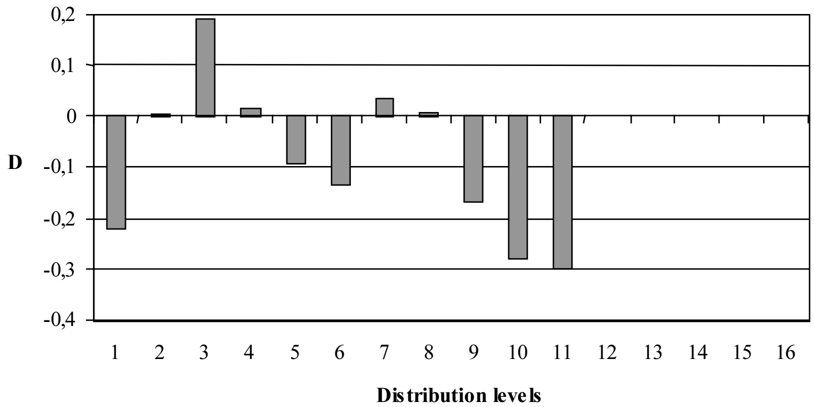

Fig.8. D – value at the corresponding levels of signal distribution by using Daubechies twentieth order filter.

Conclusions

On the base of our studies it is possible to make the subsequent conclusions:

1. The wavelets allows to realize a time-frequency analysis of the studied signal with an automatic adjustment of the window width to its frequency.
2. The series of wavelet indexes was decomposed to subspaces, that are distribution levels, and every level is a measure of frequency.
3. The type of wavelet (filter) and its order have an effect on distribution of wavelet coefficients.
4. In the case of Daubechies wavelet or Coiflet wavelet, application of the wavelet series growth causes the shift of RMS distribution to lower levels (frequencies);
5. The signal differentiation causes an essential RMS value decreasing at the levels of distribution and their shift to higher frequencies direction;
6. At the distribution levels, for which the values of RMS are maximal, the difference between the ratio of RMS at the beginning and at the end of filtered and original signals is small, but at the extreme levels (low and high frequencies) is higher;
7. Daubechies and Coiflet wavelets of the same order give similar distribution of RMS.

References

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