http://doi.org/10.35784/iapgos.3393

received: 14.12.2022 | revised: 23.12.2022 | accepted: 23.12.2022 | available online: 30.12.2022

FLAME ANALYSIS BY SELECTED METHODS IN THE FREQUENCY DOMAIN

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Abstract. *Diagnostics of pulverized coal combustion can be carried out in the field of process monitoring and analysis of measurement data. The information about changes in the flame is presented in the form of time series, which can be analyzed in the time and frequency domain. The paper presents an analysis of signals of changes in the intensity of the flame glow during pulverized coal combustion using power spectral density. On the basis of the periodograms determined using the Welch method, it was possible to determine the frequency components present in the signal.*

Keywords: flame luminosity, combustion process, power spectral density

ANALIZA PŁOMIENIA WYBRANYMI METODAMI W DZIEDZINIE CZĘSTOTLIWOŚCI

Streszczenie. *Diagnostyka spalania pyłu węglowego może być przeprowadzana w zakresie monitorowania przebiegu procesu oraz analizy danych pomiarowych. Informacje o zmianach zachodzących w płomieniu przedstawione są w postaci szeregów czasowych, które mogą być analizowane w dziedzinie czasu i czestotliwości. W artykule przedstaiono analize sygnałów zmian intesnywności świecenia płomenia podczas spalania pyłu węglowego przy użyciu gęstości widmowej mocy. Na podstawie periodogramów wyznaczonych z zastosowaniem metody Welcha możliwe było określenie składowych czestotliwościowych występujących w sygnale.*

Słowa kluczowe: intensywność świecenia płomiania, proces spalania, widmowa gęstość mocy

Introduction

Over the years, the complexity of industrial processes has increased, which has directly influenced the improvement of methods for diagnosis, detection, localization and identification of defects in various industrial fields [2, 3, 10, 12, 13]. In terms of generating electricity or heat using coal, the most important part of the process is the power boiler. The combustion process occurring in it must meet high parameters in technological, environmental and economic terms. Meeting all these conditions, despite the use of components characterized by high reliability, is a major challenge requiring various diagnostic methods.

In the diagnosis of combustion processes in the field of flame study, spectral analysis methods are used [1, 4, 14, 15]. Zhang W. at al [16] used power spectral density (PSD) to study the flame front wrinkling showing a common trend for different operating conditions. PSD has also been used to evaluate the performance of models at different frequencies during flame surface density studies [6]. In addition, the Welch method [8] is used in the analysis of laminar and turbulent flames in the frequency domain.

The article presents measured data on changes in flame intensity for two variants: stable flame and disturbance flame. In the combustion process, small changes in the flame intensity can result from actions carried out to carry out the process, for example: by activating the coal feeder. On the other hand, when disruptions occur, it is particularly important for process stability to detect and diagnose them quickly. In this paper, the analysis of measurement data was carried out in the frequency domain using power spectral density. Periodograms were determined for both flame variants using the Welch method.

1. Power spectral density

For discrete signals, the power spectral density (PSD) is a parameter that defines how power is distributed over the full frequency range in a signal. The PSD is considered a fundamental method for describing random data in the frequency domain [9]. It is determined using the following formula [5, 7]:

$$S_{xx}(\omega) = \sum_{m=-\infty}^{\infty} R_{xx}(m) e^{-j\omega m} \tag{1}$$

where: S_{xx} – power spectral density, $R_{xx}(m)$ – autocorrelation function, $\omega = 2\pi f/f_s$ – pulsation, f_s – sampling frequency of the signal.

Determination of the power spectral density using a periodogram is based on the Fourier transform of the fundamental signal x(n) and is expressed by the following equation [5, 7]:

$$S_{xx}(f) = \frac{|X(f)|^2}{N}, \tag{2}$$

where: $X(f)$ – Fourier transform.

2. Time series analysis of flame luminosity

The measurement data obtained from the combustion process comes from direct observation of the flame using a diagnostic system. The flame monitoring system allows the acquisition of information about the process in a non-invasive manner. The measurement data are one-dimensional time series representing changes in the intensity of the flame glow. The study was carried out during the combustion of pulverized coal at constant process parameters such as thermal power – 400 kW and excess air ratio $\lambda = 0.75$. More than 1.8 million observations were recorded. Two selected waveforms of changes in flame luminosity, which are characterized by an equal number of samples, were adopted for analysis. The first, variant I, corresponds to the stable flame (figure 1) and the second, variant II, is a flame with recorded disturbances (figure 2). Due to the large size of the analyzed time series, the measurement data was divided into 5 areas A-E of 363092 samples each.

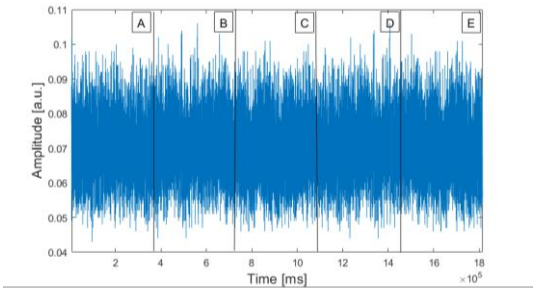

Fig. 1. Change of flame luminosity in stable flame, divided into areas A-E

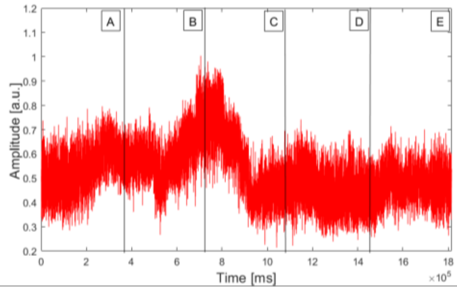

Fig. 2. Change of flame luminosity with disturbances, divided into areas A-E

Analysis of measured data in the frequency domain using power spectral density was carried out. The main purpose of using this method was to determine the spectral density estimate from the flame time series for variants I and II. PSD was determined using periodograms with the Welch method. With this approach, the input signal $x(t)$ is divided into smaller segments, and a Fourier transform is calculated for each segment using a Hamming window [11]. The result was then averaged.

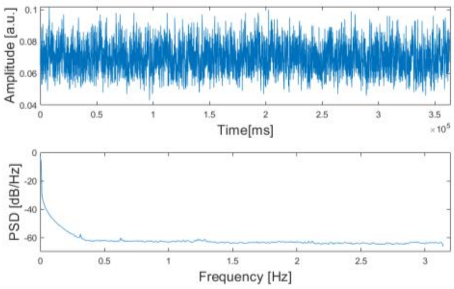

Fig. 3. Periodogram of changes in flame luminosity for stable flame in area A

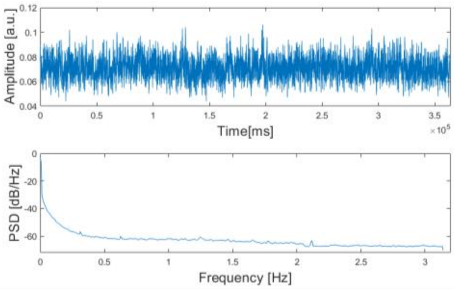

Fig. 4. Periodogram of changes in flame luminosity for stable flame in area B

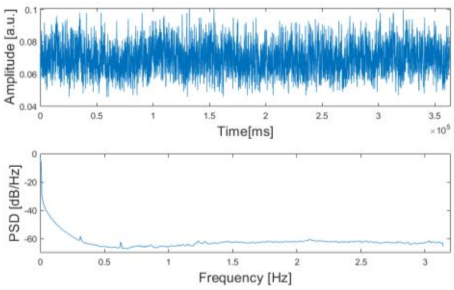

Fig. 5. Periodogram of changes in flame luminosity for stable flame in area C

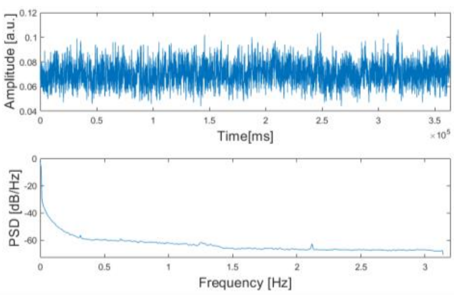

Fig. 6. Periodogram of changes in flame luminosity for stable flame in area D

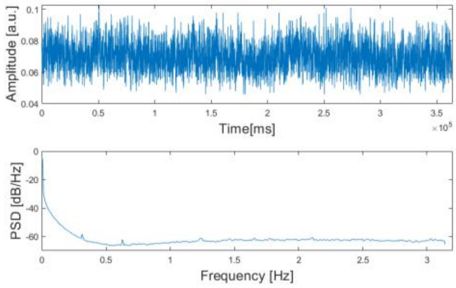

Fig. 7. Periodogram of changes in flame luminosity for stable flame in area E

Figures 3 – 7 show periodograms of changes in luminous intensity for the stable flame in areas A – E. It is observed that for the stable flame (variant I) in all areas A – E the largest frequency changes occur for low frequencies in the range from 0 to 0.5 Hz.

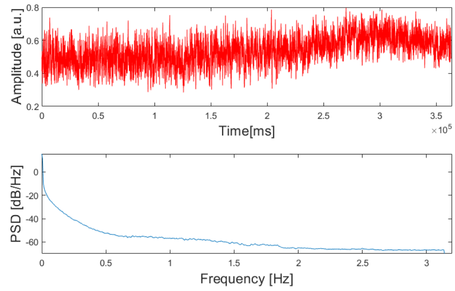

Fig. 8. Power spectral density for measured data from variant II in area A

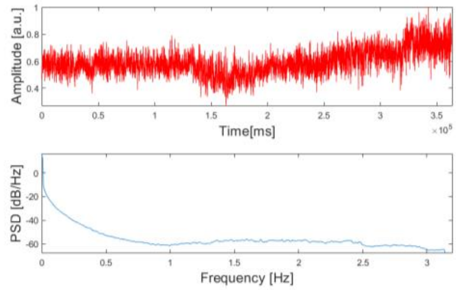

Fig. 9. Power spectral density for measured data from variant II in area B

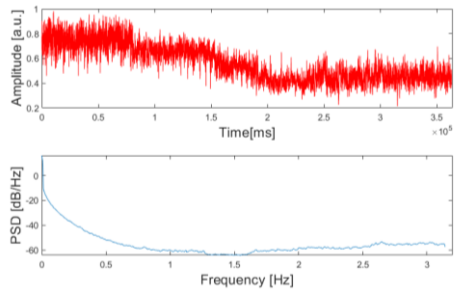

Fig. 10. Power spectral density for measured data from variant II in area C

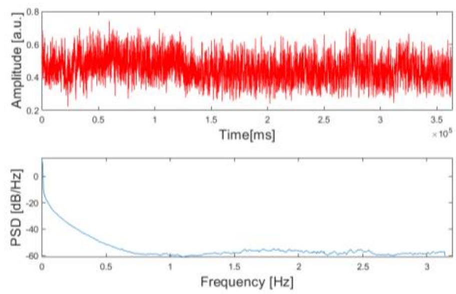

Fig. 11. Power spectral density for measured data from variant II in area D

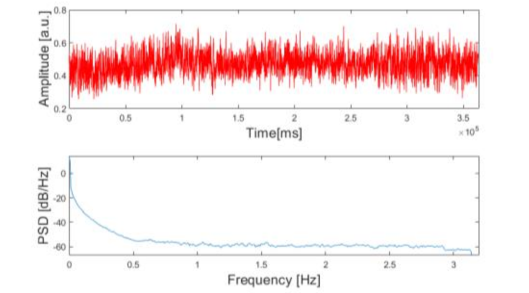

Fig. 12. Power spectral density for measured data from variant II in area E

The characteristics in figures 7 – 10 show the determined power spectral density estimates for the unstable flame (variant II) in all areas A – E. Analysis of the test results using the measurement data from variant II showed that different results were obtained for each area. The largest frequency changes were obtained in areas: A from 0 to 2 Hz and C from 0 to 1.5 Hz. In contrast, the following ranges were achieved for the other areas: B – 0–1 Hz, D – 0–1.25 Hz and E – 0–1 Hz.

The results of the power spectral density for the two flame variants in all areas A – E, indicated that in the case of a stable flame, it is possible to divide the time series into smaller areas. The division for variant I allows a detailed assessment of the changes occurring in the combustion process. In contrast, based on the periodograms for the unstable flame, it should be concluded that the division into areas is not effective. In the case of measurement data from variant II, larger time series should be adopted, which will allow a more in-depth evaluation of the process.

3. Conclusions

The acquisition of measurement data from the flame is carried out using specialized monitoring systems. They record information from the flame using a fiber-optic probe placed in the combustion chamber. The optical signals are then transferred to an optoelectronic block where they are converted to electrical form for further analysis. There are many methods for conducting analysis and diagnostics of the pulverized coal combustion process.

Time series from flame tests in the combustion process, among other things, can be analyzed in the time and frequency domains. The measurement data presented in the article for stable and unstable flame were subjected to spectral analysis of the signals. The time series for both flame variants were divided into areas A – E. The power spectral density was determined for each of them. It was estimated that for variant I of the flame, the largest frequency changes occur in the 0–0.5 Hz range. On the other hand, in the case of variant II – unstable flame – it was noted that for a full evaluation of the process, it is not necessary to divide into small areas; instead, larger time series should be used. In the unstable flame, the largest changes in frequency values were determined in area A in the range from 0–2 Hz. The use of periodograms enabled to study signals in the frequency domain.

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