THE APPLICATION OF PROBABILITY–DENSITY FUNCTION IN FIRING

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Abstract

In high-performance steamboilers of power stations pulsation in the firing chamber often occurs. Pulsation can be determined by measuring the pressure vibration. According to experience they have a stochastic character and their information content can be analyzed with the help of probability laws. The direct analytical description of such signals is not possible, these can only be referred to with statistical data, or characteristic functions.

Keywords: pressure vibration, probability–density, characteristic functions.

In establishing the combustion system of pulverized coal-fired steam boilers in power stations, the data about the predetermined quality of coal will be considered. Experience shows that in the course of operation there will be a significant deviation in the coal quality from that specified in the design due to different mining technologies and geological circumstances. The combustion stability will be influenced by this deviation essentially through the change in burning conditions.

The worsening of combustion stability could be well monitored by observing the pressure fluctuations in the combustion chamber. The real cause of the growing pressure in the combustion chamber could be judged only from characteristic data about the pressure fluctuations in the combustion chamber; it could be the quality fluctuation of the coal, or other disturbing phenomena. Flame stability deterioration caused by the reduction of the coal's heating value was discovered in the lignite heated furnaces of the Gagarin Power Station. The frequency analysis on the time function of the pressure fluctuation signal has shown that at degrading flame stability the deterministic component of the pressure fluctuations in the combustion chamber has an increasing amplitude and a decreasing frequency [1].

From a similar analysis at the Ajka Power Station it was established that the frequency of the oscillation was induced by the instability of the control system of the suction ventilators [2].

The signal analysis derived from the pressure fluctuation in the combustion chamber could also be applied in cases when the flame stability is secured by residual oil stream which is necessary to maintain operational stability. The operational uniformity of the coal feeding system or the optimum arrangement of the supporting burners could be judged as well [3].

The conditions for stable burning, formulated first by LEWIS and von ELBE, are as follows: the burning is stable if in at least one signal point the velocity of streaming and the velocity of flame propagation are equal, and of opposite direction. In the case of model burners these conditions could be easily verified, but to determine the stationary cases of complicated flames the distribution of the stream fields and flame velocity must be known. In power station furnaces, the stream in the flame is turbulent; the development of mixture and the characteristic parameters of the burning process show a stochastic fluctuation in a certain range. The stability must be defined in a more general manner: degrading stability is demonstrated by the surpassing of the given range and the strengthening of the periodical components of characteristic burning parameters. This is called in everyday practice combustion chamber pulsation; its dominant frequency range is between 0.1 and 5 Hz in pulverized coal-fired furnaces.

The strengthening of the periodical component of the pressure fluctuation is dangerous not only from the point of view of the flame stability and of the periodical mechanical load onto the furnace's structural elements, but also because it leads to material deterioration and fatigue failure. The repeated, so-called short cycle loads, originating from fire degrading, with relatively short (10 to 15 min) occurrence lead to an unexpected fall-out of the furnace [1, 4, 5].

The loads resulting from the fire degradation are easily determinable from the changing parameters of the probability density function by analyzing the deterministic components of the pressure fluctuations. Applying the signal analysis method described below, the values and duration of mechanical loads are determinable, the fall-out could be prevented, and the proper time for maintenance could be planned.

The results obtained with the probability–density function are similar to those obtained in some former experimental measurements which used the relative cumulative frequency diagram of the relative occurrence frequency of pressure oscillations regarding the same time periods, and to those obtained with the performance-density spectrum [1, 3, 6, 7].

Method for Measurement and Evaluation

The quantity of pressure fluctuation in the combustion chamber was measured with the 7261 type KISTLER piezoquartz pressure-gauge. The measurement was carried out at the steam boiler of the Pécs Thermal Power Station. The measured signals were recorded onto a GOULD 8300 high-speed register and analyzed by an ONO SOKKI CP 210 analyzer. The measured signals are of stochastic type, with more or less deterministic components. The evaluation was made with probability calculus methods in order to obtain the greatest amount of information from the measured data. From the time function the following data were determined:

- the amplitude–frequency spectrum of the signal,
- the histogram of the signal (probability–density function of the amplitude).

First, let us briefly summarize the principle of measurement evaluation. The stochastic process might be considered as a random variable whose density function varies from moment to moment with regard to the mean value of density functions, we could determine the real process with a satisfying accuracy [8] (*Fig. 2*).

The distribution function of the pressure fluctuation as a random variable is:

$$P(p) = p(\xi < p),$$

where ξ is a random variable.

The monotonous increasing function is $[P(-\infty) = 0; \quad P(+\infty) = 1]$.

The pressure fluctuation is a probability–density function of a continuous random variable:

$$p(p) = \frac{\mathrm{d}P(p)}{\mathrm{d}p},$$

i. e.

$$P(p) = \int_{-\infty}^{p} p(p)\mathrm{d}p.$$

The probability of falling between p_1 and p_2 is ($p_2 - p_1 = \Delta p$):

$$p(p_1 < p < p_2) = \int_{p_1}^{p_2} p(p)\mathrm{d}p.$$

The pressure fluctuation in the combustion chamber shows a quasi normal 'bell' curve (Gauss).

Characteristic features of this 'bell' curve are:

- its position (μ_p): determined by the pressure oscillation superimposed draught in the combustion chamber
- its height
- its width (δ_p): the distance between the inflection points and the $\frac{\sqrt{2}}{2}$th part of the curve's height.

The Principle of Measurement Evaluation

To every element of the probability event space describing the casual character of mutual effects, the stochastic process coordinates one timefunction. Put into other words: the stochastic process could be regarded as a population of time functions, the elements of which are generated by elements of the event space (*Fig. 1*).

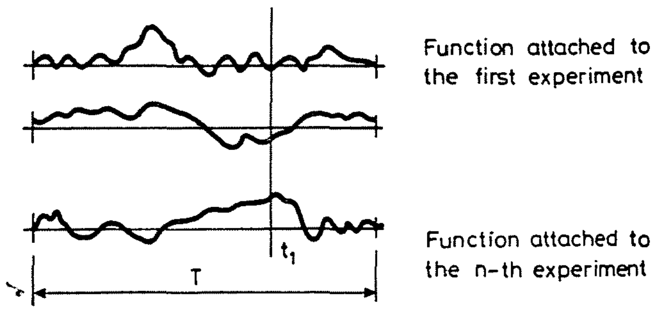

Fig. 1. The stochastic process as time function manifold

To determine the volume of the pressure fluctuation in the combustion chamber, both the height of the 'bell' curve and the dispersion around the expected value (δ_p) are suitable.

It could be seen *Fig. 3* that while increasing the probability of minor pressure oscillations, the height of density function increases, and the dispersion decreases; that means, the steepness of the related distribution function increases [3, 8].

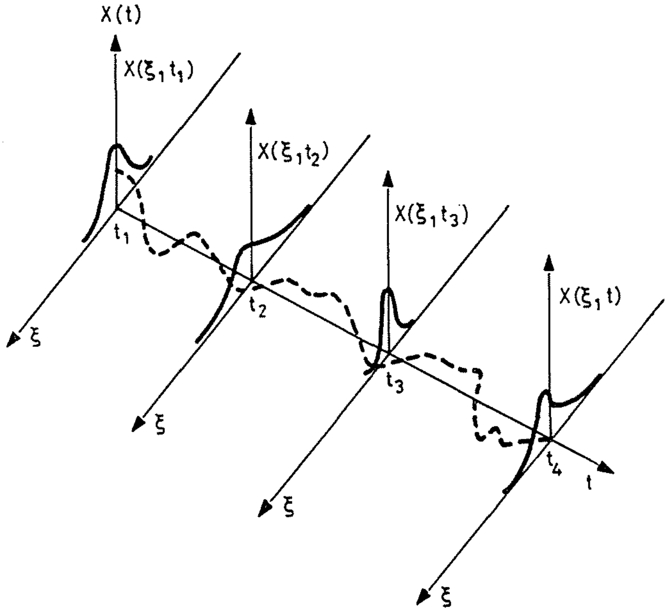

Fig. 2. The stochastic process as density function manifold

Evaluation of Measurings on CF Analyzer

Three-minute samples of pressure oscillations at the given sampling points were recorded on the high-speed register, while the primary air and loading were modified. Sampling was carried out on a FFT (Fast Fourier Transformation) analyzer as well.

From the samples recorded on the high-speed register, it was unambiguously established that the dominant frequency oscillations were in the frequency range under 100 Hz, so the range limit of the signal was prescribed as 100 Hz.

The proper operational parameters of the FFT analyzer were calibrated on the basis of this result. The analyzer processed the signals according to the Shannon sampling law.

The sampling frequency was automatically set by the analyzer according to the range limitation. The sampling frequency is $f_M = 256$ Hz. The number of the samples taken from the signals is $N = 1024$. The duration of sampling time based on this relation is 4 sec as follows:

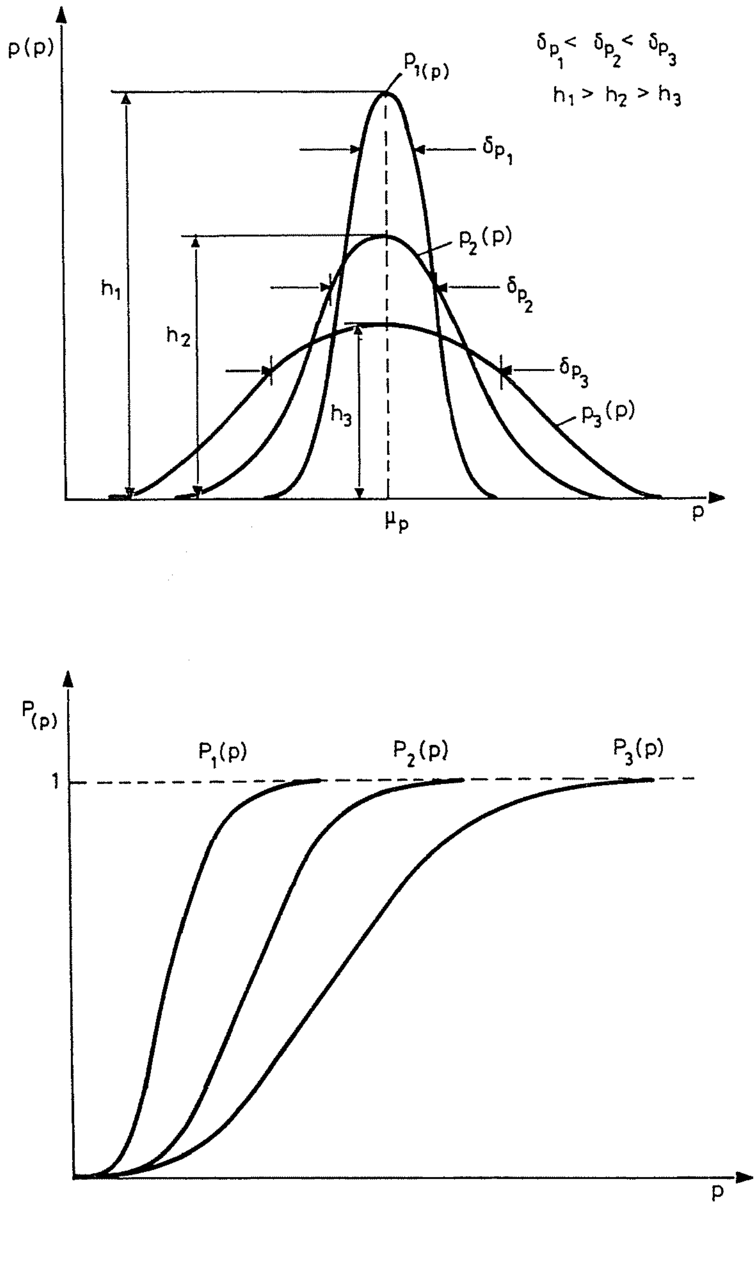

Fig. 3. Illustration of the relation between density functions and sum-frequency functions

$$T = N\frac{1}{f_M}.$$

Thirty-two samples were taken at one operational stage, and the density function of the samples was determined. The average of numbers of density functions was considered and the related time function and amplitude spectrum were plotted on the analyzer together for the sake of satisfactory accuracy of the distribution of pressure oscillations.

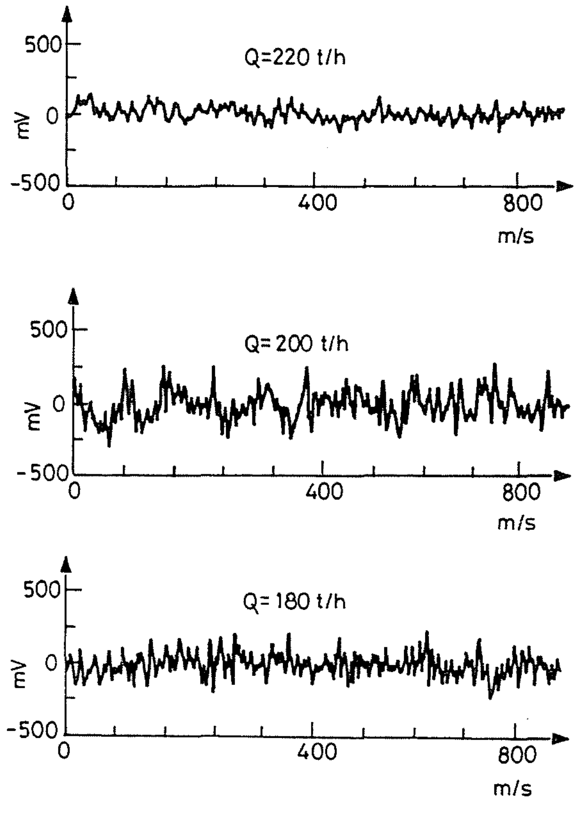

Fig. 4. Time functions of pressure oscillations in furnace chamber depending on furnace load

In *Figs 4, 5* and *6* the formation of the time function, amplitude-frequency and histogram of pressure fluctuation in combustion chamber can be seen as function of the furnace loading with constant primary air stream. The histograms containing the mean values of 16 or 32 measurements of

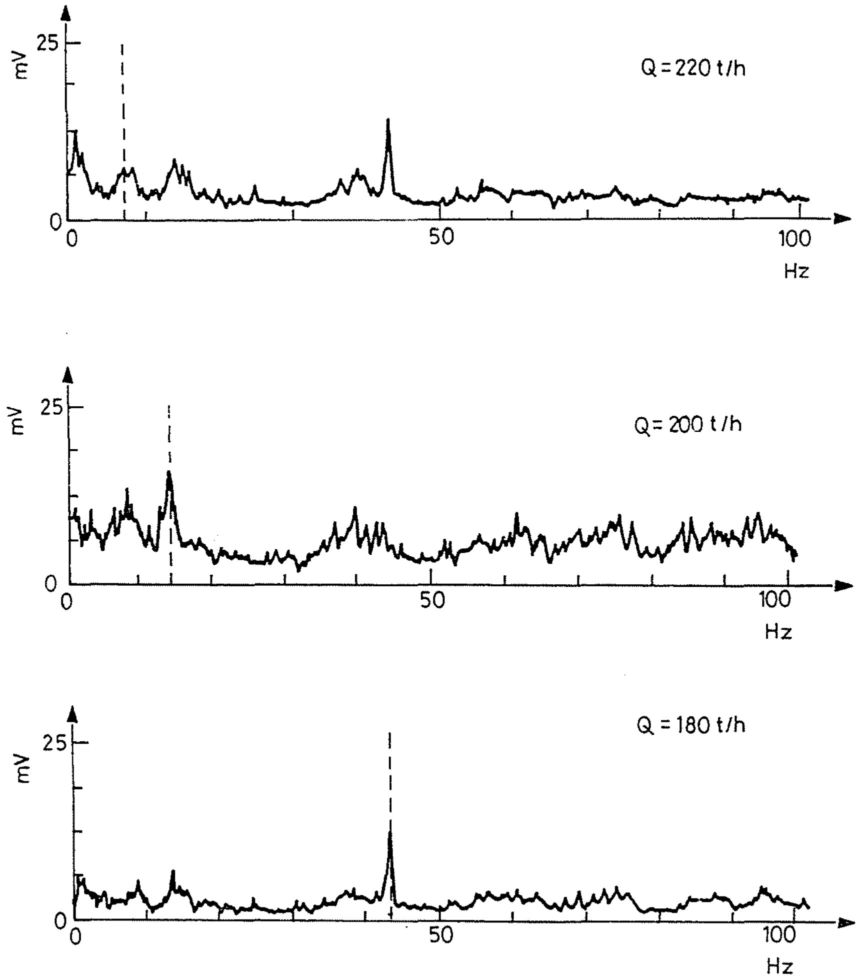

Fig. 5. Amplitude frequency spectrum of pressure oscillations density function

the pressure fluctuations in the combustion chamber offer values typical of the given operational stage.

The more narrow and high the function is, the more stable the firing is because the frequency of pressure oscillations of minor amplitude will increase in a given sample function. *Fig. 7* shows the changes of the probability density function depending on furnace load. It shows in the case of identical primary air stream the change of residual oil support [3].

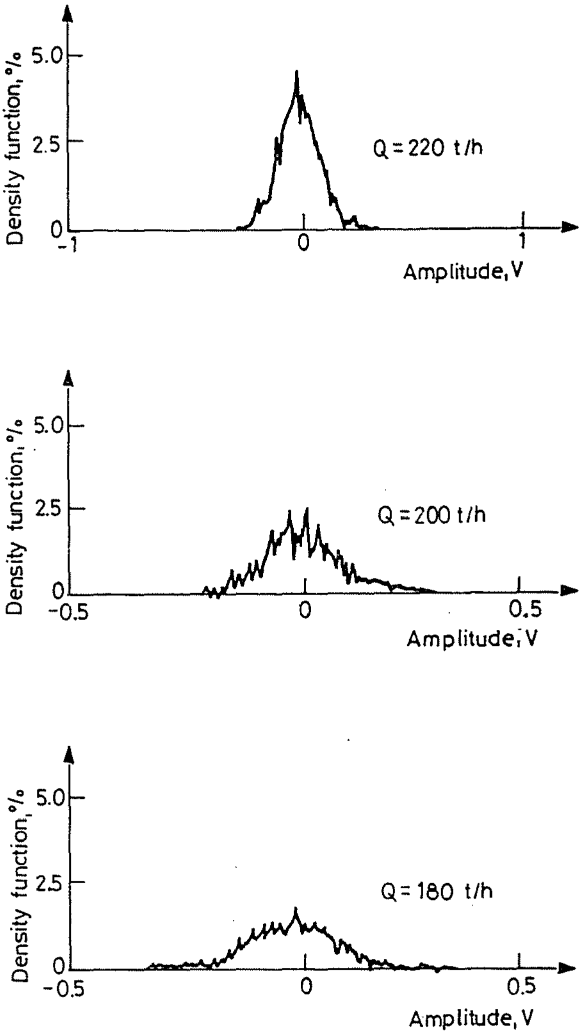

Fig. 6. Histograms of pressure oscillations

Conclusions

Considering the furnace as a signal transmitting unit, the values and changes of the input signals could be evaluated and determined by processing the information content of the output signals. With the method introduced, the identification of the whole combustion chamber system could be completed, which is one of the preliminary conditions for system optimizing. In cases of

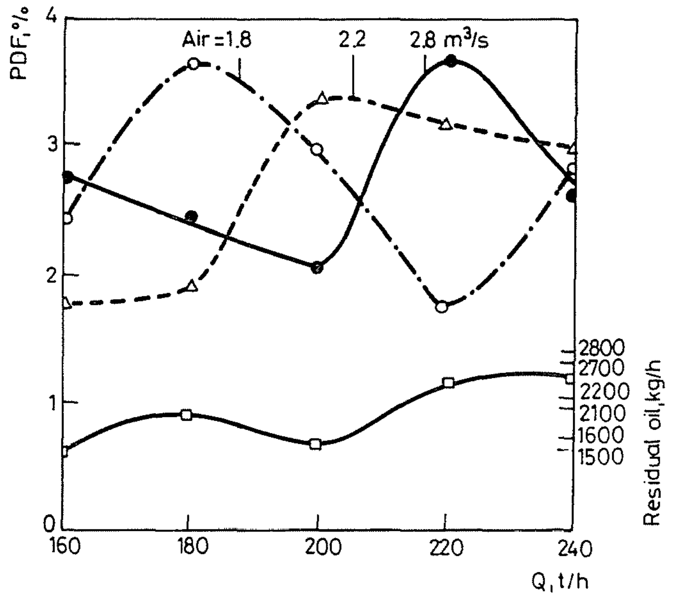

Fig. 7. Change in the probability-density function depending on furnace load

stable combustion, the pressure oscillation deriving from firing remains in a certain oscillation range and is fully stochastic (see: definition of stability).

With deteriorating firing conditions, two essential changes will take place:

1. The width range of pressure oscillation fluctuations increases,
2. Periodical components will appear in the originally stochastic signal.

The probability-density function determined by a fixed number of samples in the measurements of pressure oscillations, corresponding with computerized processing of these samples, is suitable to show the minimal alteration in the conditions of firing. This method gives a qualitatively identical result with the results of the evaluation methods (effects, density function, probability dispersion function) applied in our former experiments.

However, it is very important to know the scheduling of the directions for changes in the firing conditions, so immediate intervention will be possible long before the flame extinguishes or the mechanical load surpasses the permissible value.

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