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STOCHASTIC MODELLING OF INPUT (MATERIAL FLOW) PROCESSES IN POWER PLANT BOILERS

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Abstract

Investigation of this problem is further complicated by the fact that quality and quantity properties of the fuel coming to the power plant (thus, in the combustion chamber of the boiler) may significantly differ with time, therefore, this pulsation phenomenon can only be investigated together with testing and modelling the fuel and air flow.

Keywords: stochastic model, Semi-Markov processes, power plant boilers.

1. Introduction

During burning in combustion chamber of thermal power plant boilers — with extremely complicated physical and chemical processes — a periodic (pulsation) phenomenon can be observed. F. KAMENIECKY [1] indicates three possible factors as its reason:

- In the most simple model without thermic factors, the differential equation describing kinetic fluctuations around quasi-stationary concentrations may lead to periodic solutions in some cases;
- periodicity of relaxation fluctuations;
- thermokinetic fluctuations with considerably different heat production of the individual reactions may lead to a periodic burning process.

Investigation of this problem is further complicated by the fact that quality and quantity properties of the fuel coming to the power plant (thus, in the combustion chamber of the boiler) may significantly differ with time, therefore, this pulsation phenomenon can only be investigated together with testing and modelling the fuel and air flow [2, 3].

Based on this, we set out to build up the identification model of the burning system, which enables the optimization of the system. Thus, repeating mechanical stresses of combustion chamber structures due to the instability can be determined, consequently, they may be limited, which prevents early fatigue and rupture of the structural elements [4].

Afterwards the fuel coming to the combustion chamber should be classified, then, the dynamic process of the systematized input obtained will be stochastically modelled.

Thus, simultaneously applying the input stochastic model and the identified combustion chamber's system model, arbitrary aggregated statistics of the stress levels mentioned before can be computed.

Based on the model, past stress processes and fuel flows may be analysed, while on the basis of their expectable values future stress processes and their changes may be computed and predicted.

2. Input Process (Fuel Flow) Modelling in Heating Systems by Semi-Markov Processes

2.1. General Remarks

Basic input/output model of the heating system is as follows. Pressure measurable in the combustion chamber (pressure fluctuation) is regarded as the most important component of the output process. The pressure as a stress process has an essential influence on fatigue phenomena of the boiler wall. Further important components of the output process are the flame brightness in the combustion chamber and temperature in different heights of the combustion chamber.

The input process is understood as the multidimensional process describing composition and quantity of the fuel at the given moment.

It means description of a process complicated for modelling. The engineering approach is based on the division of fuel flow into time intervals in which the output process may be regarded as a nearly stationary one.

The empirical approach is based on the fact that in measurement series the complex fuel flow as quality and quantity properties (of K number) are treated as periodic, usually not stationary time sequences. Registration results of one year or of several years such as caloric value, moisture content, etc. can be well described, consequently, in total they can be treated as a stochastic vector process being in the time intervals determined before homogeneous stochastic processes in a sense. In any case, matching (structural and parametric estimation of) SARIMA-type time sequence models on the basis of registration results interpreted as realization of the above vector process may be regarded as an important preliminary investigation. Therefore, the fundamental task is the modelling of subsequent changes of the homogeneous sections. This modelling resembles in many aspects that of vehicles' dynamic stresses, however, this field seems to be far away [5, 6].

The final objective is to set up a Semi-Markov model capable to describe the stochastics of the homogeneous sections of the above input process with a statistically acceptable accuracy, and based on the homogeneous sections (modelling the actual fuel flows as stationary Gauss processes) the aggregated stress statistics may be computed.

2.2. General Description of the Model

Now, let us actually discuss modelling and statistical investigation of the processes of the input system of plant power boilers that may be regarded as stochastic.

Input/output model of the heating system to be tested in this paper is — in consent with the above one – as follows: the pressure fluctuation to be measured in the combustion chamber will be regarded as the output process. The pressure fluctuation as stress process plays a decisive role in fatigue phenomena of the boiler wall.

The K-dimensional process $X_t = \left(X_t^{(1)}, \dots, X_t^{(K)}\right)$, $t \geq 0$ describing the composition and flow rate of the fuel coming to the combustion chamber in the given moment will be interpreted as the input process. (Tests are performed starting from an arbitrary $t = 0$ moment.)

As different components of the fuel getting in the combustion chamber may show occasional differences, the process X_t should be interpreted as a stochastic vector process.

Following the way of the fuel from mining up to coming to the boiler, this stochastic vector process can be divided into partial time processes $(X_t; t_i \leq t \leq t_{i+1})$ where $t_0 = 0 < t_1 < \dots$ in time intervals $\Delta_i = (t_i, t_{i+1}), i = 0, 1, 1 \dots$ they may be already regarded in a sense as homogeneous (stationary) – characteristically for the given time interval – and the subsequent partial processes are independent. This division can be performed by classifying the process X_t describing the complex fuel flow into the appropriately chosen class $m = 1, 2, \dots, M$. Here it has been supposed that the interim transient intervals are relatively short in comparison to these time intervals of incidental duration.

Considering the transient sections , every Δ_1 interval will be divided into two other intervals (*Fig. 1*):

$$\Delta_i' = \left(t_1 + h_i, t_{i+1}\right),$$

$$\Delta_i'' = \left(t_i, t_i + h_1\right).$$

If the interim interval $\alpha\Delta_i''$ is short and its effect may be neglected, then we can count with the case $h_i = 0$.

The abstract logistic model is shown in *Fig. 2*. Accordingly, the model conditions are as follows:

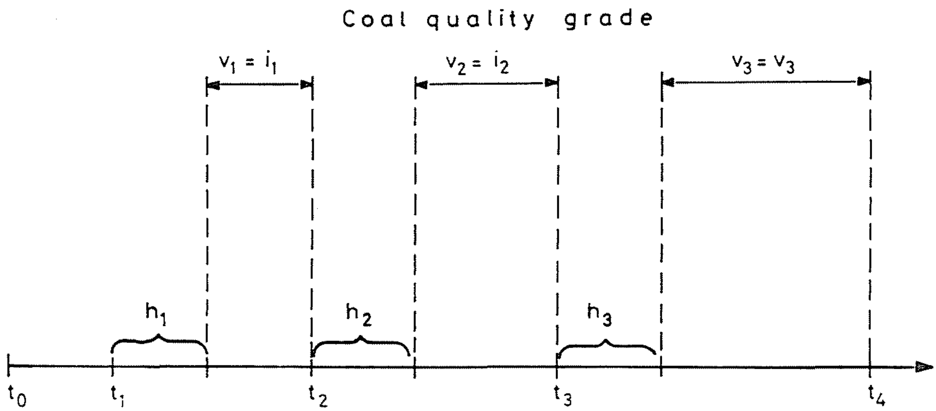

Fig. 1. Registration results considering X_t on $(t_i + h_i, t_{i+1})$ with i_j

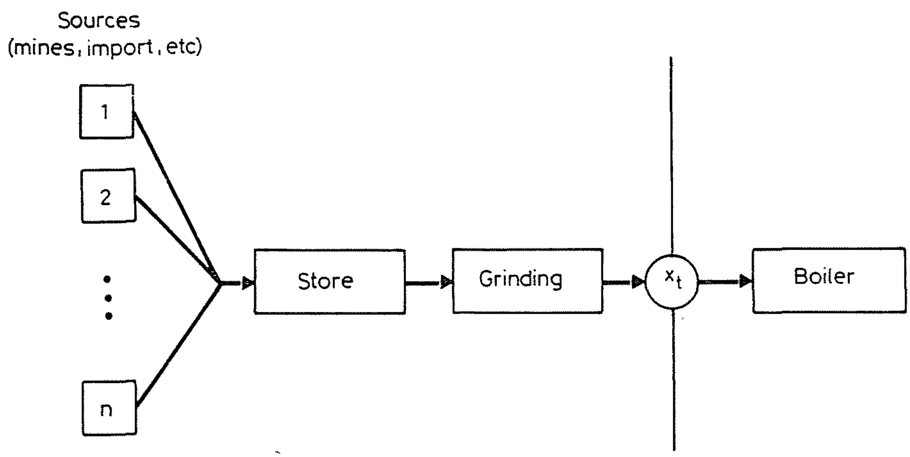

Fig. 2. Source – boiler abstract logistical model

1. Coal quality categories will be regarded as (abstract) quality grades coming from the primary sources (mines, import).
2. After reception (maybe from several sources) the various abstract qualities may mix, thus, new abstract qualities may appear.
3. The model will be interpreted starting from the cross-section demonstrated in *Fig. 1* (as a cut).
4. The relation between the real sources and the (abstract) coal quality processes appearing at the cut should be determined in a separate logistical test.

$$x_t = \begin{array}{l} \left[\begin{array}{c} x_t^{(1)} \\ x_t^{(2)} \\ \bullet \\ \bullet \\ \bullet \\ x_t^{(k)} \end{array}\right] \end{array} \begin{array}{l} \text{— Flow intensity} \\ \text{— Caloric value} \\ \left.\begin{array}{l} \\ \\ \\ \end{array}\right\} \text{Composition} \end{array}$$

Fig. 3. Input vector process describing the quantity composition and flow intensity of the fuel coming to the combustion chamber at the moment t

Now the assumption is obvious that the boiler's input process may be modelled as a Semi-Markov model due to the coal flow's nature, where the conditions of the embedded Markov chain correspond to the different abstract coal qualities (Appendix 1) appearing after coming to the coal store from different sources and after grinding. Let $\mathcal{M} = (1, 2, \ldots, M)$ denote the possible abstract coal quality grades (there are M pieces of them) and let $\big(m(t), t \geq 0\big)$ denote the actual category defined by the vector $\mathbf{X}(t) = \big(X^{(1)}(t), \ldots, X^{K}(t)\big)$ describing the coal quality coming to the boiler at the moment t and the flow intensity (Appendix 1). If $t_1, t_2, t_3 \ldots$ define the subsequent (incidental) moments in which the quality of the coal getting into the boiler changes (occasionally considering transient sections), then $\nu_n = m(t_n + 0)\big(m(t_n + 0)$ means the right limit value $\big)$, the abstract coal quality grade in the interval (t_n, t_{n+1}) is just.

Thus, in accordance with the above, the sequence $(\nu_n, n = 1, 2 \ldots)$ gives a Markov chain with any transient probability matrix $\mathbf{P} = (P_{ij})_{i,j=1}^{M}$, and the distribution of the length $T_n = t_{n+1} - t_n$ of subsequent homogeneous sections (with unchanged quality grade) only depends on the values $\nu_n = i$ and $\nu_{n+1} = j$.

Let $F(x; i, j) = P(\tau_n < X | \nu_n = i\ \nu = j)$, $n \geq 1$, $i, j, \varepsilon\mathcal{M}$ denote this in the forthcoming.

Thus, the quality grade does not change in a homogeneous section, however, this does not mean that the vector describing the coal quality in the moment t has a constant value (*Fig. 4*). The assumption that the process $X(t)$ describes in a homogeneous section a stationary Gauss process whose parameters (expectable value function and covariance function) are determined by the actual quality grade (corresponding to this homogeneous section) meets the engineering approach. On the basis of the above

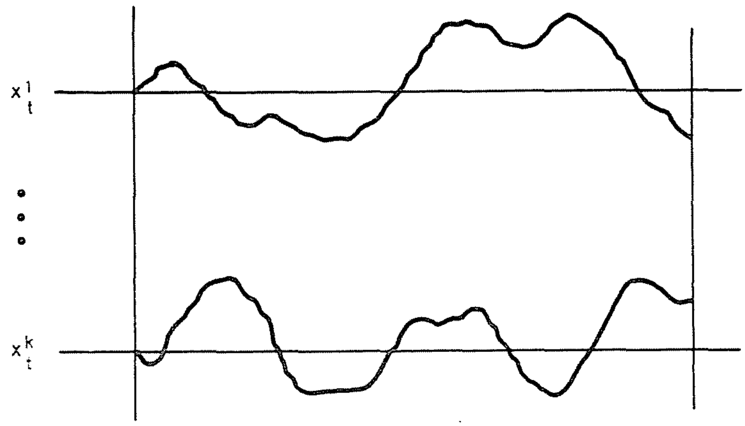

Fig. 4. Registration results considering X_t on $(t_i + h_i, t_{i+1})$ with i_j

fundamental model the following modelling task can be performed and the following problems can be solved.

1. Determination of the condition space (the individual conditions are the 'abstract qualities' appearing in the cut).
2. Description of the changes in the coal quality grade (condition):
   a) Estimation of the ergodic (irreducible, periodic) transience probability matrix

$$\mathbf{P} = \left(\frac{P_{11}\, P_{12}\, P_{1M}}{P_{M1}\, P_{M2}\, P_{MM}}\right)$$

   of the embedded homogeneous Markov chain (ν_n) and of the expected values determined by the distributions $F(x; i, j), i, j \varepsilon \mathcal{M}$.

$$T_{ij} = \int_0^\infty x dF(x;\, i, j).$$

   b) Estimation of the parameters of the Gaussian processes corresponding to the individual coal quality grades.
   c) Computation of the ergodic distribution $\Pi = (\Pi_1, \ldots, \Pi_M)$ of the embedded Markov chain $(\nu_n, u \geq 1)$ (which exists in accordance with our conditions) on the basis of the estimated matrix $\mathbf{P}$.

Thus, processing appropriate statistics, the model of the input fuel flow can be constructed.

If S_j denotes the time in which the system is in the quality grade m_j during the period (O,S), i.e. summation of those sections of the period (O, S) where $m(t) = m_j$, then with the notation $T_i = \sum_{j=1}^{M} P_{ij}T_{ij}$ the relation

$$\lim_{S\to\infty} \frac{S_i}{S} = \frac{\Pi_1 \Pi_1}{\sum\limits_{j=i}^{M} \Pi_j T_j}$$

holds with probability 1 following from the convergence theorem for Semi-Markov processes.

Appendix

Multiparametric source space:
- flow intensity
- temperature after grinding (pressure)
- caloric value
- ash content
- moisture content coal quality
- sulphur content
- grain size.

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