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# STATISTICAL IDENTIFICATION OF DYNAMIC MODELLING OF PULSATION IN PULVERIZED COAL FIRED STEAM BOILERS

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## Abstract

The identification model of the firing system was set up, and on this basis, the system can be theoretically optimized. On the basis of the results yielded the repeating mechanical stress level of the combustion chamber's structures due to instability can be determined and, thus, limited, which prevents early fatigue and rupture of the structural elements.

*Keywords:* dynamic model, pulsation, coal fired, identification model.

## 1. Introduction

Quality of coal used in power plants significantly varies with mining conditions, in some cases they do not even achieve the quality grade indicated in boiler's design parameters. In the case of unfavourable service conditions (e.g. bad quality coal gets in several stores at the same time) this can lead to considerable firing stability problems.

Consequently, periodic combustion instability may develop in some boilers fired by pulverized coal with a frequency 0.2 to 5 Hz when firing with lignite. The repeating loads resulting from it are especially harmful in membrane wall boilers because eigenfrequency of this kind of boilers is about 3 Hz, thus, excitement coming from firing can lead to wall resonance and in most cases to its strong stresses.

Firing with low-quality coal differing from the design data may result in everyday boiler tube bursts and fracture of structures.

Low-frequency stress processes causing fatigue of tube lines and structures have not been measured by any method either continuously or periodically yet. By the help of incorporated gauges in former measurement series combustion worsening could only be detected after 15 to 20 minutes. Therefore relatively short stresses occurring repeatedly called as short cycle fatigue stresses may remained undetected, which can result in unexpected breakdown of the boiler [1].

For safe control of these combustion processes measurement and control models have been worked out. These models are based on the assumption that combustion measurement tasks usually involve systems global behaviour of which can be well approximated by definition of their transfer characteristics. Because of the task's nature it is essential how the system produces these transfer characteristics, i.e. internal structure of the model and its interactions should be known. In these cases control models and system identification models are 'established' that can reliably define these transfer characteristics and are able to provide indirect information on interactions within the system.

This means that the firing equipment can be considered – regarding their behaviour – as dynamic systems. In this case, registration results of pressure in combustion chamber may be considered – after proper technological classifying of immeasurable input (fuel flow) processes – as their reactions that can be described by discrete stationary stochastic processes.

On this basis structure and parameters (input filter + dynamic member) of the linear dynamic system – after preliminary analyses in the non-parametric time and frequency range – can be determined by the help of the well-known filter-identification transfer function or state space representation by the estimation methods Maximum Likelihood or Prediction Error.

On the basis of the concrete identification and prediction models we can obtain reliable predictions and comprehensive stress statistics (level of cross-section numbers, extremal distributions, etc.) can be prepared by the help of (stochastic) data characteristic of boiler operation.

Through the method elaborated we set out to establish the identification model of firing systems by which the system optimization according to the given criteria can be performed.

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.

This problem has been discussed in several studies in FRG and Czechoslovakia but they were limited to investigation of time functions of the pressure fluctuation in the combustion chamber. In the research report prepared at our Department was stated for the first time that through computer-aided signal analysis essentially more information could be obtained on the changes of firing stability and on the changes of the deterministic and stochastic components of the signal.

## 2. General Identification Model

On the basis of the model approach outlined above the system describing the 'flame pressure fluctuation' measured in the combustion chamber is as follows:

Hypostatized abstract excitation of the given fuel will be considered as a non-observable (immeasurable) Gaussian white noise process $u(t) = e(t)$ with the expected value of zero (*Fig. 1*).

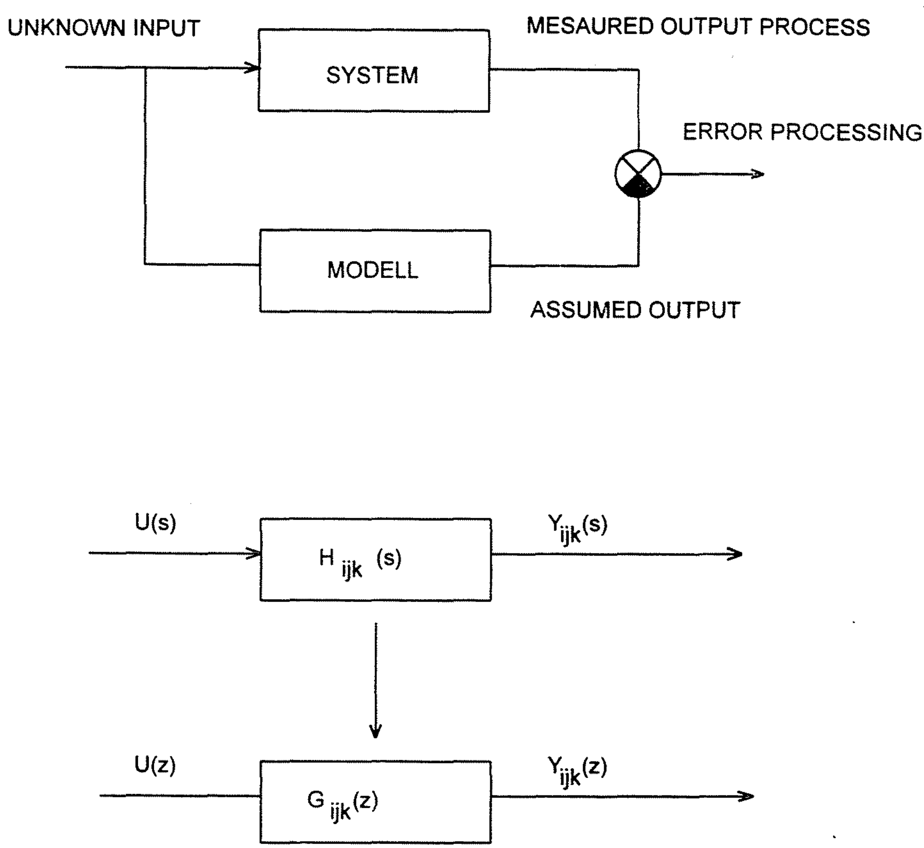


*Fig. 1.* Modelling and identification process

The un-observable source noise of the flame pressure excitation coming from the burnability of the given fuel will be interpreted as follows.

In a given fuel, share of inflammable and noninflammable 'particles' (units) depends on various (geometric, material, etc.) variables independent from each other. Therefore it can be assumed that on the basis of the theorem of central distribution their sum can be approximated by a variable of normal distribution. This fluctuation of the fuel units can be again regarded as independent in time. Thus, they may be understood as time sequences of independent random variables of normal distribution, i.e. as a white noise process.

When the relation between the assumed abstract input excitation and the measured flame pressure fluctuation $y_{ijk}(t)$ (where spatial coordinates $i, j, k$ can be arbitrarily chosen) will be described as a stationary process in a linear or bilinear system, i.e. taking the $^*(i,j,k)$ additional measurement noise independent from the input into account, which can contain all the other disturbing processes with burning, we get the following system equations:

$$y_{ijk}(t) = \int_0^\infty g(\tau)u(t-\tau)d\tau + \xi(t) \tag{2.1}$$

for the linear case, and

$$y_{ijk}(t) = \int_0^\infty g_1(t)u(t-\tau)d\tau + \int\int_0^\infty g_2(\tau,\delta)u(t-\delta)d\tau d\delta + \xi(t) \tag{2.2}$$

for the bilinear case where $g_1(t)$ is the weight function of the linear system, while $g_2(t,\delta)$ is the two-variable weight function of the bilinear member.

As $E(u(t)) = 0$ and $E(\xi(t)) = 0$, thus, in the linear case $E = (y_{ijk}(t)) = 0$, or by a simple computation may be made equal to 0.

$$E[y_{ijk}(t)] = 0 + \int\int_0^\infty g_2(\tau,\delta)R_{uu}(\tau-\delta)d\tau d\delta,$$

where because of $R_{uu}(\tau-\delta) = \delta(\tau-\sigma)$ (here $\delta$ is the Dirac function)

$$E[y_{ijk}(t)] = \int\int_0^\infty g_2(\tau,\tau)d\tau.$$

Now let us consider the above system description in the frequency domain. In this case we obtain that symbolically

$$y_{ijk}(s) = H(s)U(s), \tag{2.3}$$

where $U(s=j\omega)$ is the white noise range, while $Y(s)$ is the Laplace transformation of output, and $H(s)$ is the transfer function.

In bilinear case

$$Y_{ijk}(s) = H_1(s)U(s) + H_2(s_1, s_2)U(s_i)U(s_2), \tag{2.4}$$

where the two-variable transfer function can be given in the following realizable form

$$H_2(s_1, s_2) = \frac{B(s_1, s_2)B(s_1)B(s_2)}{A(s_1, s_2)A(s_1)A(s_2)}, \tag{2.5}$$

where $H_2(s_1, s_2)$ is the two-variable transfer function which should meet the prescriptions of the two-variable Laplace transformation [6, 8, 9].

The equivalent state space model being in accordance with the above is in the time range:

$$x(t) = Ax(t) + bu(t),$$
$$Y_{ijk}(t) = C^T x(t) + \beta_0 u(t),$$

where

$$\mathbf{A} = \begin{vmatrix} 0 & 1 & 0 & \dots & 0 \\ 0 & 0 & 1 & \dots & 0 \\ \cdot & & & & \\ 0 & 0 & & \dots & 0 \\ -\alpha_n & -\alpha_{n-1} & & \dots & -\alpha_1 \end{vmatrix}; \mathbf{b} = \begin{vmatrix} 0 \\ 0 \\ \cdot \\ 0 \\ 0 \end{vmatrix} \text{ and } \mathbf{C} = \begin{vmatrix} \beta_n - \beta_0\alpha_n \\ \beta_n - \beta_0\alpha_{n-1} \\ \cdot \\ \\ \beta_1 - \beta_0\alpha_1 \end{vmatrix}$$

in the observability form, and

$$x_2(t) = A_2 x_2(t) + b_2 u(t),$$

$$y(t) = C_{2T} x_2(t) + \beta_0 u(t),$$

where

$$\mathbf{A}_2 = \begin{vmatrix} -\alpha_1 & 1 & 0 & \dots & 0 \\ -\alpha_2 & 0 & 1 & \dots & 0 \\ \cdot & & & & \\ -\alpha_{n-1} & 0 & 0 & \dots & 1 \\ -\alpha_n & 0 & 0 & \dots & 0 \end{vmatrix}; \mathbf{b}_2 = \begin{vmatrix} \beta_n - \beta_0\alpha_n \\ \cdot \\ \cdot \\ \cdot \\ \beta_1 - \beta_0\alpha_1 \end{vmatrix}; \text{ and } \mathbf{C}_2 = \begin{vmatrix} 1 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{vmatrix}$$

in the *controllability form*. In addition to the transfer function and state space representation we could study the ARMAX representation, too, but we disregard this because of its smaller practical importance. We do not close with the bilinear model in state space representatively, see [2, 3, 6, 7].

However, when describing discretized equivalent time sequence models used in practical applications we will supply also the equivalent discrete bilinear condition space descriptions.

## 3. The 'Concrete' (Theoretical) Identification Model

If the input cannot be observed or measured, then the system will be represented by the Wiener-Ito integral in the case of a discrete model. Here let be the discrete white noise $w_t$ described by a $\sigma_2$ square standard deviation and $w_1$ stochastic spectral measure of which is $w(d\omega)$ according to the following spectral representation

$$w_t = \int_0^1 e^{i2\pi\omega} w(d\omega) \tag{3.1}$$

and in the continuous case $w_t$ corresponds to a Wiener process. (In this case, the method will be realized by the substitution $s = i\omega$) [5, 8]

$$y_{ijk}(t) = \int_{-\infty}^{\infty} \varepsilon^{i\omega t} G_{ijk}(i\omega) W(d\omega), \tag{3.2}$$

where

$$G_{ijk}(i\omega) = H(i\omega) = \frac{B(i\omega)}{A(i\omega)} \tag{3.3}$$

while in bilinear case

$$y_{ijk}(t) = y_{ijk}(\text{linear case}) + \int \int_{-\infty}^{\infty} e^{i(\omega_1+\omega_2)t} G(i\omega_1, i\omega_2) W(d\omega_1, d\omega_2), \tag{3.4}$$

where $y_{lin}(t)$ is the linear model (according to the form above) and

$$G(i\omega_1, i\omega_2) = \frac{B_{12}(i\omega_1, i\omega_2) B_2(i\omega_1) B_2(i\omega_2)}{A(i\omega_1 + i\omega_2) A(i\omega_1) A(i\omega_2)}. \tag{3.5}$$

Also here we have to take into consideration the additional noise processes, i.e. $y(t) = y_1(t) + \xi(t)$ where $\xi(t)$ is an ARMA stationary process, which is independent from the $y_1(t)$ process through the transfer function $\beta_0(\omega)/\alpha_0(\omega)$. In discretized form

$$\xi_t = \frac{\beta_0(z)}{\alpha_0(z)}, \qquad \varepsilon_t = G_0(z)\varepsilon_t,$$

where $\varepsilon_t$ is a discrete white noise process.

The discrete one- and two-dimensional time sequence models equivalent to the continuous ones are in the frequency range in linear case

$$y_{ijk}(t) = G(z)u(t) + \xi(t) = \frac{B_1(z)}{A(z)}W_t + G_0(z)\xi_t \qquad (3.6)$$

and in bilinear case:

$$y_{ijk}(t) = G_1(z)u(t) + G_{12}(z_1, z_2)u(t_1)u(t_2). \qquad (3.7)$$

The concrete estimation contains the following steps using the spectrum and bispectrum formulas known from the literature:
1. Estimation and computation of the spectrum (in bilinear case that of the spectrum and bispectrum) by the known methods [4, 6].
2. Parameter estimation in knowledge of the estimated structure (it involves estimation of the order of the one- or two-variable transfer functions).

In the case of the spectrum $I_k$ and the bispectrum $I_{jk}$ the concrete estimation means the solution of the following extreme value task.

In linear case:

$$\sum_k \left[I_k - f(w_{ki}\oslash)\right]^2 \to \min_{\oslash} \qquad (3.8)$$

and in bilinear case:

$$\sum_k \left[I_k - f_1(w_{ki}\oslash)\right]^2 + \left[card(\Delta)\right]^{-1} \sum_i \sum_j \left[I_{ij} - \Phi(w_i, w_j, \oslash)\right]^2 \to \min_{\oslash}, \qquad (3.9)$$

where $\Phi$ denotes the free parameters in the spectrum $f(z, \Phi)$ and bispectrum $\Phi(z_1, z_2, \Phi)$, further the summation goes for all frequencies $w_i, w_j \varepsilon \Delta$ and card $(\Delta)$ denotes the quantity of summands.

Afterwards, the obtained (estimated) discrete model parameters can be transferred by the known methods into the continuous model parameters [8].

## 4. Summary

The identification model of the firing system was set up, and on this basis, the system can be theoretically optimized. On the basis of the results yielded the repeating mechanical stress level of the combustion chamber's structures due to instability can be determined and, thus, limited, which prevents early fatigue and rupture of the structural elements.

In the second part of the task the fuel getting into the combustion chamber will be classified, and the dynamical process of the arranged input obtained will be stochastically modelled. Applying the input stochastic model and the identified combustion chamber system model simultaneously, arbitrary aggregated statistics of the stress levels may be computed. Using the model, the former stresses and fuel flows may be analyzed, and expected values and changes of the stress processes may be computed and predicted.

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