The dynamic stochastic model of a boiler unit

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Abstract. The goal is to develop a model that takes into account the boiler unit furnace device dynamics. The D J Box and G Jenkins technique used to identify the steam production process is considered. As the object of the study selected a boiler unit, which is quite complex and interconnected. Its description is a dynamic stochastic object with uncontrollable indignant influences. Statistical methods have obtained a mathematical model, which can be used to predict and regulate dilution in the boiler furnace.

1. Introduction
The boiler unit efficient operation is impossible without a high-quality control process organization at each of its stages. Starting from water treatment, water supply to the boiler drum and ending with ensuring the furnace chamber [1] correct operation. It is the furnace chamber that is the boiler unit operating system most important elements one. The boiler unit work as a whole depends on how the combustion process is carried out. For its proper operation, it is necessary to exclude all possible disturbing effects in the damage form to the flue lining and poor-quality fuel supplied to the furnace. It is also necessary to ensure the fuel most complete combustion in the furnace volume, providing the fuel required ratio and air in the combustion chamber [2]. This article is devoted to a dynamic stochastic model development that takes into account the relationship between the steam flow and the flue gas temperature in the boiler unit rotary chamber.

2. Model identification
Constructing a time series model process is to determine the appropriate model class for the experimental data under study. As mentioned above in this study, the Box and Jenkins methodology will be used to identify time series, and the resulting model is called the PIMAAA model (the pro-integrated moving average auto-aggression model) [3].

Further, for further research, we present the time series obtained as a passive experiment result in the boiler unit BKZ 420-140 figure 1.

The time series contains the parameters of the furnace chamber operation during steam production at the BKZ-420 boiler unit. Steam consumption, gas temperature in the rotary chamber. The data volume for the study is 1,800 measurements with a sampling rate of 10 seconds.
Since these parameters measured values are in different ranges: temperature and flow, for further analysis, it is necessary to bring these time series to a single form. To do this, we will perform an alignment procedure for each row. As a result, we will get standardized time series. This will allow statistical methods to use for further data processing [4]. For visual data analysis, we will plot the time series under study graphs figure 2.

| 1 Steam_consumption | 2 gas_temperature |
|---------------------|-------------------|
| 1 246.26            | 436.94            |
| 2 243.45            | 436.94            |
| 3 243.45            | 436.94            |
| 4 242.15            | 436.94            |
| 5 240.90            | 436.39            |
| 6 240.90            | 436.39            |
| 7 238.25            | 434.79            |
| 8 238.25            | 434.79            |
| 9 236.92            | 433.68            |
| 10 236.92           | 433.68            |
| 11 235.46           | 433.03            |
| 12 235.46           | 432.37            |
| 13 235.46           | 431.82            |
| 14 234.07           | 431.27            |
| 15 234.07           | 431.27            |
| 16 235.44           | 430.72            |
| 17 235.44           | 430.72            |
| 18 236.73           | 430.17            |

Figure 1. The studied parameters time series.

In order to bring the above time series to a stationary form, according to the method [5][6], for each series, the difference time series were obtained using the difference-taking operator:

\[ x_t = \nabla^d x_t; \quad y_t = \nabla^d y_t, \text{ by } d > 0 \]

where \( d \) is the order of difference; \( x_t, y_t \) are the time series normalized values:

Figure 2. The studied time series graph.
where $\bar{X}_t$, $\bar{Y}_t$ - the series mean values, $\sigma_x$, $\sigma_y$ - standard deviation.

Bringing the series to a stationary form makes it possible to use the cross-correlation functions method to determine in the model structure such time delays [7], for which the coupling coefficients between the steam flow rate and the flue gas temperature are most significant [8].

To trace the dynamics in various communication channels between the parameters, an initial data correlation analysis was carried out by constructing a cross-correlation function, figure 3.

This graph visual analysis shows a strong correlation between the studied parameters. This dependence does not allow us to draw an unambiguous conclusion about the time intervals at which the steam flow rate significantly affects the temperature in the turning chamber, but it helps to determine the mutual correlation coefficients significance [9].

Next, we will make a studied time series preliminary identification to establish the model selected class correspondence with the available experimental data. The main criterion for identification is the autocorrelation and partial autocorrelation functions behaviour.

Let us construct for the autoregressive and moving average (AMA) investigated time series models [10]:

$$\alpha_t = x_t - \sum_{i=1}^p \Phi_i x_{t-i} + \sum_{j=1}^q \Theta_{t-j} \alpha_{t-j};$$

$$\beta_t = y_t - \sum_{i=1}^p \Phi_i y_{t-i} + \sum_{j=1}^q \Theta_{t-j} \beta_{t-j};$$

where $\alpha_t$, $\beta_t$ - aligned series, respectively, for the input and output difference series; $\Phi_i$ - parameter values for auto regression model; $\Theta_{i,j}$ - parameter values for the moving average model; $p$ - the autoregressive model order;

$q$ - the moving average model order.

The time series' the temperature in the reversing chamber is described by the PIMA AAA autoregressive model (3 1 1) $p=3$; $q = 1$.

The time series steam flow is described by the PIMA AAA autoregressive model (1 1 1) $p = 1$; $q = 1$.

To obtain estimates $p$, $q$, $\Phi_i$, a non-linear least-squares algorithm was applied [11] [12].
3. Building a dynamic stochastic time series model

To construct a stochastic model, let us consider the gas temperature in the rotating chamber as the output parameter and the steam flow rate as the input.

Below is the aligned time-series cross-correlation function. Figure 4.

Figure 4. The aligned output row VKF using the input.

The steam flow rate influence dynamic stochastic models on the temperature in the rotating chamber were obtained using the Box-Jenkins method in the models class

\[ y_t = \delta^{-1}(B) \omega(B) \cdot x_{t-b} + n_t, \]

where \( B \) is the operator to shift back one step, \( b \) is the lag parameter, \( n_t \) is the noise component. [13].

The developed dynamic stochastic models are presented below:

\[ Y_t = (0.103 \pm 0.038) \cdot x_{t-4} + (0.103 \pm 0.038) \cdot x_{t-8} + (0.106 \pm 0.038) \cdot x_{t-9} + N_t \]  

(3)

The sample autocorrelation function model study \( N_t \) allows identifying the noise model in the PIMAAA form (1 1 2):

\[ \varphi_{z_t} = \left(0.957 \pm 0.012\right) \cdot \varphi_{z_{t-1}} - \left(1.063 \pm 0.040\right) \cdot a_{t-1} - \left(-0.424 \pm 0.039\right) \cdot a_{t-2} + a_t \]

\[ \left(1 - 0.957 \pm 0.012\right) \cdot N_t = \left(1 - 1.063 \pm 0.040\right) \cdot B + \left(-0.424 \pm 0.039\right) \cdot B^2 \cdot a_t \]

\[ N_t = \frac{1 - 1.063 \cdot B - 0.424 \cdot B^2}{1 - 0.957B} \cdot a_t \]

The transfer function - noise combined model final form for flue gas given communication channel temperature in the rotary chamber - steam consumption:

\[ Y_t = (0.103 \pm 0.038) \cdot x_{t-4} + (0.103 \pm 0.038) \cdot x_{t-8} + (0.106 \pm 0.038) \cdot x_{t-9} + \frac{1 - 1.063 \cdot B - 0.424 \cdot B^2}{1 - 0.957B} \cdot a_t \]

4. Diagnostic test

The obtained models are analyzed for the steam flow rate influence actual process adequacy on the temperature in the rotary chamber using a diagnostic check [13], carried out in two stages: first, \( x^2 \) - statistics for the residual errors' autocorrelation function values \( r_{aa}(k) \) as \( Q = (N-s-b-r); \sum_{k=1}^{r} r \cdot aa^2(k), \) where \( N \) is the number of observations, \( k \) is the autocorrelations and cross-correlations

\[ ... \]
maximum delay, $S$ is the dynamic stochastic model right-handed parameters number, $r$ is the left-handed' parameters number.

Then it is calculated $\chi^2$ statistics using cross-correlation functions $r_{aa} (k)$ between the equalized input series $\xi_t$ and the residual error series, $a'$ as $H = (N-s-b-r) \sum_{k=1}^{N} r (k)$.

In the first case, $Q$ is compared with $\chi^2$ - a distribution with $K-p-q$ freedom degrees, and in the second - $H$ is compared with $\chi^2$ - a distribution with $K-r-S$ freedom degrees [14].

Table 1 shows the coefficients' values $\chi^2$- diagnostic test statistics for autocorrelation and cross-correlation functions.

**Table 1. Coefficient values $\chi^2$ statistics.**

| Input                   | Output                        | Freedom degrees number | N   | Freedom degrees number | $Q$  |
|-------------------------|-------------------------------|------------------------|-----|------------------------|------|
| Steam consumption       | Rotary chamber temperature   | 30                     | 38.45 | 30                     | 43.8 |

A diagnostic check for autocorrelation and cross-correlation functions using the values of $\chi^2$ statistics does not give grounds for doubting the model adequacy [15].

**5. Conclusion**

As the research result, a model was obtained that allows to assess of the steam consumption effect on the temperature in the boiler unit rotary chamber.

The model can be used to predict the temperature in the boiler unit furnace depending on the steam consumption.

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