Control System Simulator for Steam Boiler Parameters

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Abstract: - The paper presents the research results related to control of the steam boiler parameters: drum level, furnace pressure and steam pressure. It was developed the mathematical model of the water-steam system and furnace part of the boiler. Also, the paper presents the algorithm for real time detection of model parameter variations. In this context a correction method, validate through simulation was developed.

Key-Words: - steam boiler, steam pressure, furnace pressure.

1 Introduction
Related to the systemic point of view, the boiler is frame in the category of the MIMO system (more input more output).

It is important to choose the adequate input-output pair, witch to assure an efficient control for the output variables through the input variable, with maxim effect and without main perturbation for the other output variables [2].

We will choose as the output variables that measurable variable how permit the obtaining a complete information on the state of the boiler in each moment of time (Fig. 1).

The dependence between input-output variables:
- The steam pressure \( p \) in the drum is a variable how depend on the boiler steam flow \( D_p \) and the turbine steam flow \( D_c \).
- The furnace pressure depending on the resulted gaze flow \( G_p \) and the evacuated gaze flow \( Ge \).
- The water level in the drum depending on the water flow, the boiler steam flow \( D_p \) and the turbine steam flow \( D_c \).

- The fuel flow \( B \) is an independent variable, because it isn’t affected by the other variable and it may be modified with the conveyor.
- The air flow, from the burning process, it must to has a value how corresponding with fuel flow \( B \).

We will choose the supply water flow for the control of the level drum, and the fuel flow for the control of the furnace pressure [3].

For the control of the steam pressure in the drum we will choose the heat transfer coefficient through radiation \( K_{Re} \), such as will be presents in chapter 2.

2 The automatic control structure of the steam boiler
Writing the balance thermal equation for burning process we obtain the next equation:

\[
\frac{d(m_H H_g)}{dt} = A \cdot C_{pd} \cdot T_A + K_{comb} \cdot B \cdot H_en -
\]

\[
-G_e \cdot C_{pg} \cdot T_e - K_{Re} (T_m^4 - T_s^4)
\]

(1)

We make the next assumption [4]:
- The burning gases are treated like a perfect gas.
- The calorific power of fuel it is consider equal with the net heat and deviation from the ideal burning is represented by the burning coefficient \( K_{comb} \).
- The heat exchange to furnace zone (convection, conduction and radiation) and the water from pipes, at the saturation temperature \( T_s \), is equivalent with a direct heat exchange through radiation. \( T_m \) is the middle temperature of burning gases.

Fig. 1. The input-output variable for boiler
From the low of perfect gases we can approximate:

\[ m g H g' = \frac{VC_{vg} P_f}{R} \]  \tag{2} 

where:
- \( V \) - the volume used from the gases in the furnace zone;
- \( C_{vg} \) - the specific heat of gases at constant volume;
- \( R \) - the perfect gases constant;
- \( P_f \) - the furnace pressure.

Writing the equation (1) depends by the furnace pressure \( P_f \) with \( T_g \) and \( T_m \) calculated, result:

\[ \frac{VC_{vg}}{R} \frac{dP_f}{dt} = AC_{pa} T_A + K_{comb} BH \sqrt{C_N} - G_s C_{pg} T_g - K_w (T_m^4 - T_s^4) \]  \tag{3} 

We consider that in the drum exist two phases (steam and liquid in equilibrium) and the measured liquid level don’t give as an exact information about the existent liquid quantity from the drum and we must to introduce the supplementary correction about water flow at the input of the drum.

The balance material equation for water from the drum is:

\[ \frac{dm_w}{dt} = W_e - D_e - D_s \]  \tag{4} 

where:
- \( m_w \) - the effective liquid mass from the drum;
- \( D_e \) - the turbine steam flow from the drum;
- \( D_s \) - the water outflow (through the broken pipes).

\[ \frac{dm_w}{dt} = (\rho_{ls} - \rho_{vs}) \frac{dV_s}{dt} + (V_{in} - V_l + V_l(1 - \alpha)) \frac{dp_{in}}{dp} \frac{dp}{dt} - V_l \frac{d\alpha}{dt} (\rho_0 - \rho_{vs}) \]  \tag{5} 

where:
- \( V_l \) - the liquid volume used in the drum;
- \( V_{in} \) - the descending pipes volume;
- \( V_{in} \) - the liquid volume measured with a transducer level;
- \( V_s \) - the volume used from steam in the liquid space;
- \( V_v \) - the volume used from steam in the drum;
- \( \alpha \) - the fraction used from steam in \( V_v \);
- \( \rho_0, \rho_{vs} \) - the density at saturation for steam and liquid.

The balance thermal for the water and steam from the drum and the boiler pipes:

\[ \frac{dP_f}{dt} = \frac{M_m C_n}{C_a} \frac{dP_f}{dp} + M_t \frac{dH_t}{dp} + M_l \frac{dH_l}{dp} - (V_{in} + V_l + V_{in} + V_v) + \\
+ (H_{in} - H_{ls}) [V_l + V_{in} + V_v (1 - \alpha)] \frac{d\rho_s}{dp} + \\
+ (V_{in} - V_l + V_{in}) \frac{d\rho_s}{dp} + \\
- W_l (H_{in} - H_l - D_e (H_{in} - H_{ls}) + (1 + \beta) \ast \\
\ast (H_{in} - H_{ls}) W_t - D_e - D_s + K_{R} (T_m^4 - T_s^4) \]  \tag{6} 

where:
- \( M_m \) - the metal mass of the drum and pipes;
- \( C_n \) - the specific heat of the metal;
- \( M_t \) - the total liquid mass from drum and pipes;
- \( M_s \) - the total steam mass from drum;
- \( H_{vs}, H_{ls} \) - the steam and liquid content heat at saturation;
- \( \beta \) - the steam fraction who condense in the drum;
We can express the measured liquid level depending on the liquid volume measured \( V_{in} \).

\[ V_{in} = \frac{y \cdot 1 - R^2}{2} \frac{1}{2} (R - L) R \sin \frac{\gamma}{2} \]

\[ \cos \frac{\gamma}{2} = 1 - \frac{L}{R}; \]

\[ V_s = \pi \cdot R^2 \cdot 1 - V_{in} \]  \tag{7} 

In the equation (1) to (6) we don’t know exactly and will be modify on the time of functioning of the boiler the next variables:
- the necessary water flow \( W_e \), controlled by the measured level;
- the heat transfer coefficient through radiation \( K_{ra} \);
- the burning coefficient \( K_{comb} \);

The variation speed of the steam pressure in the drum is proportional with the difference between the boiler steam flow and the turbine steam flow and inverse proportional with the thermal accumulation capacity of the boiler.

So, we can write the equation:

\[ \frac{dp}{dt} = \frac{D_p - D_e}{C_a} \]  \tag{8} 

where \( C_a \) is the thermal accumulation capacity.

The numerical value of the coefficient \( C_a \) depending on the next variable:
- The steam flow supplied in the boiler in stationary regime;
- The metal mass of the vaporization system;
- The rotation \( m \in (0,1:0.8) \)
where \( w_a \) is water quantity from the boiler and \( D_{max} \) is the maximum steam flow.

Conform to this specification, result:

\[
\frac{D}{D_{max}} \frac{dt}{h} = \frac{t}{t}
\]

(9)

For stationary regime:

\[
D_{p0} = D_{c0} = D_0
\]

(10)

For dynamic regime:

\[
\frac{d\Delta p}{dt} = \Delta D_{P} - \Delta D_{C}
\]

(11)

After integration we obtain:

\[
\Delta p(t) = \Delta p(0) + \frac{1}{C_a(D_0)} \int_{0}^{t} (\Delta D_{P}(\tau) - \Delta D_{C}(\tau))d\tau
\]

(12)

\[
\Delta p(t) = \Delta p_1(t) + \Delta p_2(t)
\]

(13)

\[
\Delta p(t) = \frac{K_{\Delta P}}{sT_{\Delta P}} \Delta D_{P}(s) - \frac{K_{\Delta P}}{sT_{\Delta P}} \Delta D_{C}(s)
\]

(14)

where:

\[
K_{\Delta P} = \frac{P_{N}}{D_{max}}, \quad T_{\Delta P} = \frac{C_{a0}P_{N}}{D_{max}}, \quad C_{a0} = C_a(D_0)
\]

According to equation (14) result the block scheme from Fig. 2:

\[
\Delta D_{P}(s) \rightarrow K_{\Delta P}/sT_{\Delta P} \rightarrow \Delta p(s)
\]

\[
\Delta D_{C}(s) \rightarrow K_{\Delta P}/sT_{\Delta P} \rightarrow \Delta p(s)
\]

3 The experimental results

The experimental results are obtained by simulation under MATLAB Simulink.

- The air flow \( A \), from the burning process, it must to has a value how corresponding with fuel flow \( B \): \( A = k \cdot B \), \( k = 2.5 \).

If we modify the coefficient \( k \), using the control structure from Fig. 3 we can determinate the correction which be done in the model of the boiler to assure the tuning parameters correction’s of the controllers.
4 Conclusion

We have realized the simulated model of the boiler and the control structure for the boiler.

This structure of simulation permit as to estimate the correction which be done in the model of the boiler to assure the tuning parameters correction’s of the controllers.

We intend to realize a program, which can be offer to users the dedicated software for fault detection and the solution for the value corrections which be done in the model of the boiler.

References:


