CONTROL OF BIOMASS BOILER WATER TEMPERATUR USING SLIDING MODE CONTROL SYSTEM

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Abstract— **Medium scale biomass temperature control is a specific field of control issues where one of the most important features is cost effectiveness. It means that any kind of control system improvement should be done with the lowest possible additional costs. Generally, the basic control of such kind of boiler regulates temperature of outlet heating water. This control can be also performed by a conventional or advanced control.**

Although the main problem of this study is the construction of the model of biomass boiler for control purposes, our task deals with technology of boilers and principles of its inner processes as well. Creation of the model comes out not only from these important findings, but also from experimental data collected during measurements in real operation. Heat and mass balance calculations were made according to these data and they serve to precise dynamic properties of experimental unit for biomass combustion.

Based on the derived mathematical model of the biomass boiler, here is possibility to enhance the control by additional algorithms that are responsible for extended optimization functions. In this paper, an advanced process control such as sliding mode control system (SMC) is used to control the temperature of the boiler water. The results show that SMC has strong immunity for the disturbance and the varying of process parameters.

Index Terms: **Biomass Boiler; mathematical model, PID, SMC.**

I. INTRODUCTION

Unlike to classical boiler which operates on natural gas or oil fuel, the grate or biomass boiler requires high quality of combustion air due to non-homogenous of biomass fuel and varying process parameters such as moisture [1].

With biomass boilers, over 90% of problems in combustion control consist of fuel quality fluctuations. Also jamming of fuel feed system causes problems for the heaters especially with screw feeder conveyor based systems. Obtaining the necessary amount of power from highly fluctuating low quality fuel is challenge for process and control engineers. Problems are also reflected to the fact that the fuel feed controller does not always work properly due to the lack of data of accurate measurements about the fuel bed [2].

In addition to biomass boiler technology, control system design has also a major impact on economical and implementation of more biomass boilers in real industries. According to above mentioned problems, few researchers focus on implementation more sophisticated control system such as sliding mode control system [8]. Mostly, the control system of the existing biomass boiler depends on classical PID control systems which are not effective in controlling the outlet boiler temperature due to process time delay and highly disturbances of the process parameters

Although, the dead time can be overcome by using the famous smith predictor technique [3], but other effects such as uncertainty and varying process parameters cannot be treated using classical PID control system.

Recently, new techniques of control systems such as model reference adaptive control MRAC, fuzzy logic control have been applied for process control [4, 5] but rare of them were applied for biomass technology due to difficulties for obtaining real mathematical model for biomass boiler. The objective of this study is to develop an advanced control technique depends on a mathematical model derived from real experiment data which had been gained during observation of the operation of biomass boiler for several years [6, 7].

II. BIOMASS BOILER STRUCTURE

The biomass boiler consists of the main components as shown in Figure.1. Biomass feeder is a mechanical underfeeding grate, meaning that the fuel is fed from below the grate by a screw conveyor to the middle of the biomass boiler. The grate consists of circular rings, half of which are fixed and the other half is moved by a hydraulic system following a circular motion. With this

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slow rotating movement the fuel spreads around the grate and moves forward.

With biomass boiler the ignition is assumed to take place near the grate surface. This is a result of fuel high moisture content and heat radiation from the hot grate. This way the combustion front propagates from down to up and as reaching the surface of the fuel bed, the next wave of combustion propagates from top to down. However, information from previously illustrated behavior is uncertain, for example due to the fact that the primary air is not pre-heated and cools the fuel bed [5].

The air feed is divided into two phases: primary and secondary air. Primary air is fed from below through the grate, and secondary air is fed tangentially from above the grate. Both of the air feeds are not pre-heated. Secondary air is fed tangentially to ensure as perfect mixture of combustion gases as possible. Primary air is divided into three zones; First zone is for drying, second zone for paralysis and third zone for combustion of carbon residue [2]. Several temperature sensors have been installed in the boiler to measure combustion zones on the grate and water heating.

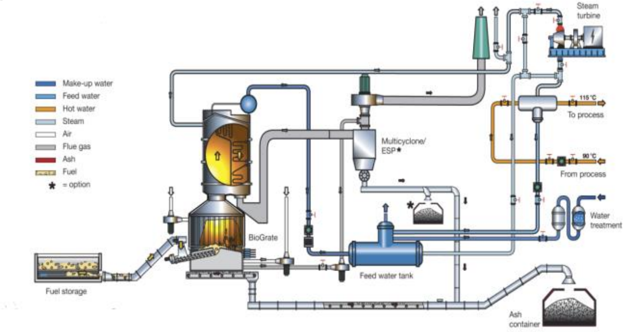

Figure. 1. Structure of Biomass Boiler

The dynamic equation of temperature of heating water of biomass boiler was derived from real experiments observations done by three years of research [1]. The model expressed the second order transfer function with extremely time delay.

$$G(s) = \frac{0.06e^{-480S}}{27225S^2 + 330S + 1} \qquad (1)$$

III. CONTROL SYSTEM DESIGN

A. *Classical three mode PID control*

Figure. 2 shows the block diagram of classical PID controller with a closed loop system. A control system with a PID controller contains three parts, the sensor coupled to the plant (process), decision in a controller element and action through an output device (actuator). When the controller receives data from the sensor, it calculates the error by subtracting the measured value from the pre-defined set point [3].

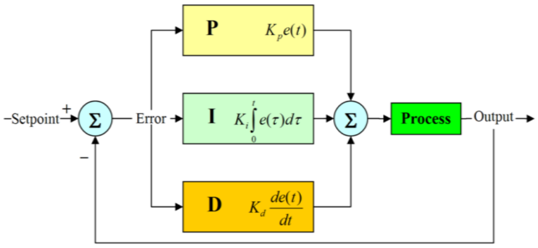

Figure. 2. Three Mode PID Controller

The transfer function of this type of PID controller in S-domain is given

Fig. 2. Three mode PID controller

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s} \qquad (2)$$

Where K_p, K_i and K_d are proportional, integral and derivative gain, respectively.

Control of biomass boiler was designated for heating water temperature which represents the core issue in our design. In this case, a PID control with smith predictor technique was implemented to our system. Ziegler-Nichols method [3] was used in order to obtain the parameters of controller such as:

$$G_c(s) = 72.3\left(1 + \frac{1}{510S} + 472.5S\right) \qquad (3)$$

B. *Sliding mode control system*

Sliding mode control SMC system is an important control method that ensures robustness and delivers a systematic method to overcome stability problems and reliable performance. On the other hand, this tradeoff between the modeling and reliable is allowed to clarify the control design process [8]. Figure. 3 shows the block diagram of SMC system.

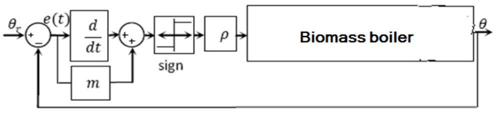

Figure. 3. Sliding Mode Control System

Taking for example a nonlinear plant with Θ_r and Θ represent the scalar input and output variables. The control objective is to force the output of the plant Θ to track a desired input Θ_r , to make the error in output, e(t)=Θ_r – Θ tends to vicinity of zero after an acceptable transient time. The design of first order SMC includes two phases:

- Phase 1: Sliding Surface Design
- Phase 2: Control Input Design

Phase1: defining a certain scalar function of the system state, for example:

$$\sigma(x):\ R^n \rightarrow\ R \qquad (4)$$

Note Usually, the sliding surface is depending on the tracking error e(t) along with its derivatives.

$$\sigma \; = \sigma\,(\,e\,,(\,\dot{e}\,)\ldots,(e)^{K}) \qquad (5)$$

The most usual selection for the sliding manifold is a set of linear equations as follows:

$$\sigma \; = e^{(k)} + \textstyle\sum_{i=0}^{k-1} c_i e^{(i)} \qquad (6)$$

The number of derived equations to be involved (the "k" coefficient in equation (6)) has to be as k = r-1, where r is the input-output relation degree and c_i are arbitrary coefficients.

A classical formula for the sliding surface is shown below, where it depends on a single variable m.

$$\sigma = (\frac{d}{dt} + m)^{k}\, e \qquad (7)$$

if k=1 then: $\sigma = \dot{e} + me$

if k=2 then: $\sigma = \ddot{e} + 2m\dot{e} + m^{2}e$

The selection of the variable "m" is almost random, and describes the exclusive pole of the resultant "reduced dynamics" when the system is in sliding.

The second phase is to discover a control action that directs the system's routes to the sliding manifold. The control action can be expressed mathematically as follows:

$$U = -\,\rho sgn(\sigma) \qquad (8)$$

$$\text{Where:} \quad U = \begin{pmatrix} -\rho & \sigma > 0 \\ \rho & \sigma < 0 \end{pmatrix}$$

One disadvantage of using sliding mode is the creation of chattering on the system, which affects the actuator like valves. Figure 4 shows the chattering that exists in the system.

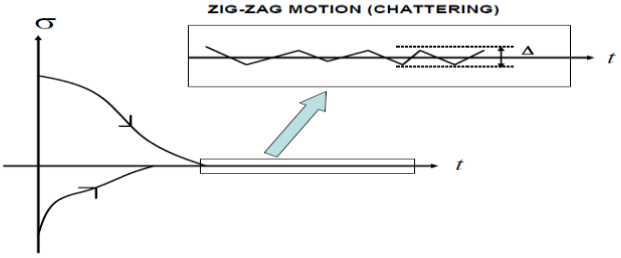

Fig. 4. Chattering Phenomena of Variable σ

IV. NUMERICAL RESULTS

The model is verified on environmental of SIMULINK/MATLAB when PID and SMC have been simulated under some circumstances such as process disturbances.

Figure 5 and 6 shows the PID block diagram and step response of the system when the temperature of the water was set to 80°C.

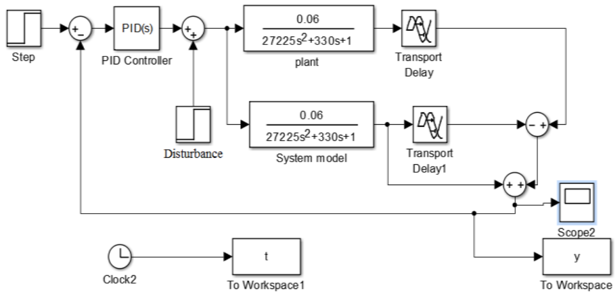

Fig. 5. Simulink of PID Control with Smith Predictor

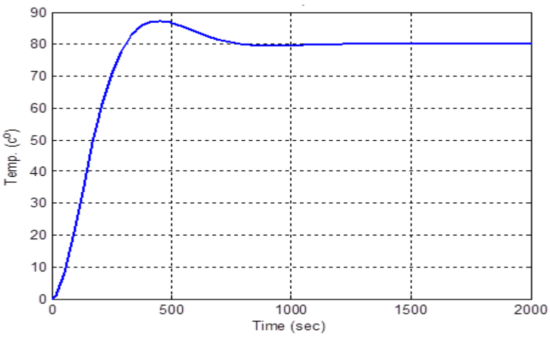

Fig. 6. Step Response of the PID Control (without Disturbance).

Figure 7 shows the effect of disturbances on the step response when the temperature of water was set to 80°C.

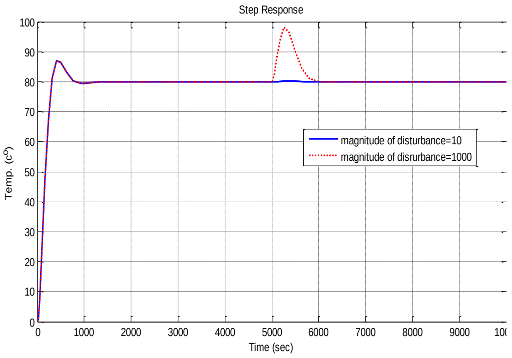

Fig. 7. Step Response of the PID Control (with Disturbance)

Now the first order SMC with smith predictor [3] is applied in order to eliminate the time delay and increase the system performance.

According to the equation (1), we found out that the relative degree between the output Θ(t) and the input

$\Theta_r(t)$ is r=2 and then K=r-1=1. By assuming that the gain parameters p=1 and m=0.3 which are chosen arbitrary, then:

$$\sigma = e + \dot{e} \qquad (9)$$

Figure 8, 9 and 10 shows the SMC block diagram, the step response (without the disturbance effects) and the control signal, respectively.

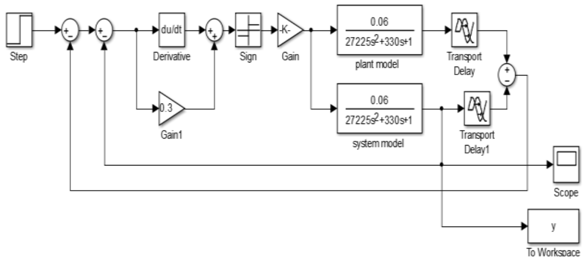

Fig. 8. Simulink of SMC Control System

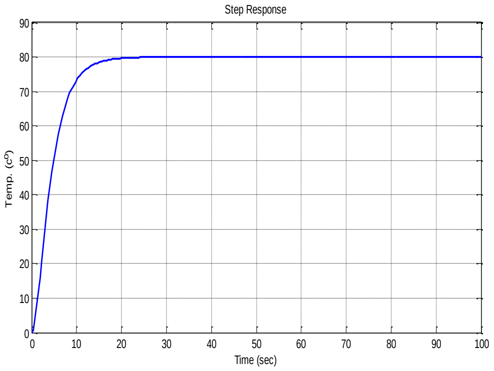

Fig. 9. Step Response of SMC Control System (without Disturbance)

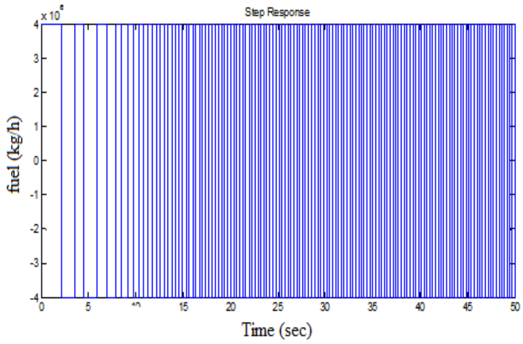

Fig. 10. SMC Control Signal with Chattering

Now, the disturbance to SMC system is applied. However, the chattering phenomena can be reduced by using the saturation function sat(σ) instead of sign(σ) function given in equation (8).

Figure 11, 12 and 13 shows the SIMULINK block diagram of SMC, step response with disturbance and control signal, respectively.

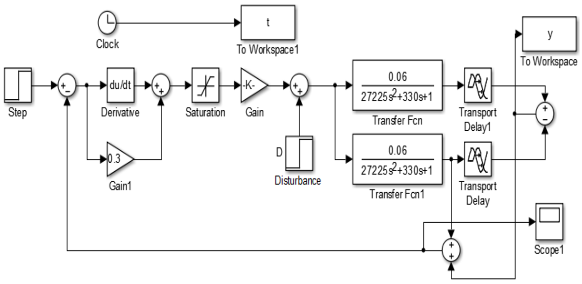

Fig.11. Simulink of SMC Control (with Disturbance)

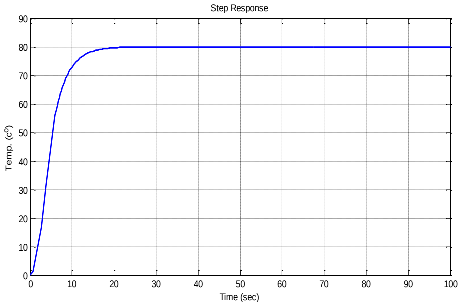

Fig.12. Step Response of SMC Control (with Disturbance)

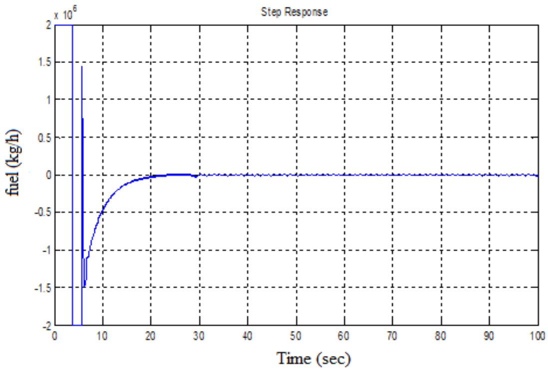

Fig.13. SMC Control Signal without Chattering

The table 1 illustrated the difference between the classical PID control and the advanced first order SMC.

Table 1. Comparison between PID and SMC

	PID control	**SMC control**
Settling time	750 sec	20sec
Overshoot	10%	Non
Steady state error	Non	Non
Disturbance	Effected	Rejected
Rise time	200 sec	8sec

V. CONCLUDING REMARKS

One can notice that using classical PID control for biomass boiler be quite possible and can produce remarkable results as shown in Figure. 6. The long time delay of the process can be deleted by adding smith predictor technique to the control loop.

However, we can see that the long settling time (about 750 sec) and large disturbance has serious impact on the response of PID controller as shown in Figure. 7.

By insertion the SMC system for biomass boiler, it can clearly be seen that the settling time has been shortened considerably and the disturbance has no effect on the response signal as shown in figure. 9. The disadvantage of SMC was the chattering phenomena on the control signal. However, the chattering can be reduced by insertion of SAT function instead of SGN function as shown in Figure. 13. However, there is a sudden transient at the beginning of simulation time due to small effect of chattering.

We conclude from the above results that applying SMC control system can give amazing results over PID control although the chattering problem does exist. SMC has ability to improve the control system by speeding up the control response and reject the disturbance

We plan further to synthesize biomass boiler control using second order sliding mode control system in order to overcome the transient effect of chattering and improve the control accuracy.

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