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A Novel Control Method for Drum Level and Pressure Basing on Dynamic Surface

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Abstract

A novel drum level and pressure simultaneously control method is developed using the dynamic surface control method in this paper which takes account of the output power of units and load change .Certain first-order low-pass filters are introduced into the designing process to avoid the occurrence of high-order derivatives of elements in the system which makes it easy to implement in practical applications. The proposed control method is effective in compensating for the disturbance of load and fuel. Simulation results show that the dynamic surface control method still ensures an accurate result, even if the loads change in a great and parameters of the controlled plant change significantly.

Keywords*: drum dynamics; dynamic surface control; filer method*

1. Introduction

There are dramatic changes in the power industry because of deregulation. One consequence of this is that the demands for rapid changes in power generation are increasing. This leads to more stringent requirements on the control systems for the processes. It is required to keep the processes operating well for large changes in the operating conditions. One way to achieve this is to incorporate more process knowledge into the systems. There has also been a significant development of methods for the unit system. There are so many conditions need to be controlled for system requirement and conventional PID control strategy cannot achieve good control performance for multiple loops. Presently, engineers and technicians adopt some new control methods, such as advanced PID algorithms, Fuzzy control methods, neural network and *etc.* to solve the complex control problems of the power units. A nonlinear long range predictive controller based on neural networks is developed to control the main steam temperature by Liu [1]; A generalized predictive control was proposed to control the drum water level in the paper [2]; A composite control strategy based on variable universe fuzzy logic control integrated with immune and self-tuning PID control is presented in the paper [3], It has stronger robustness and better self-adaptive ability, which can be adaptive to the change in the parameters of the controlled plant. Most control methods are only valid for specific conditions or less than three variables.

Advent of Backstepping method in end of the twentieth century was a key breakthrough for nonlinearity of some control tasks. The paper [4] used Backstepping method and advanced ones to design steam temperature controller which satisfies the stability of heat exchanger system and improves the economy and safety of unit plants. A novel robust nonlinear control strategy based on Backsteping technology is investigated for a class of strongly nonlinear control problem in the paper [5]. The paper [6] adopted dynamic surface control with a low pass filer technique, which overcomes the problems of

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repeatedly differential and complicated structure during the controller design based Backstepping methods. Advanced dynamic surface control combines the control of relatively simple structure and satisfied characters of transient process.

In this paper, a novel controller is design with dynamic surface method for the system of three controlled variables, that are unit load, drum water level and pressure before turbine. In this control system, control variable is the feed water and turbine generator valve. Firstly, A nonlinear model for steam generation systems is introduced which are a crucial part of most power plants. Secondly, system controller is designed adopting dynamic surface control method, avoiding the effect of operation conditions changing in the expression of the control law. Thirdly, the system stability is verified using Lyapunov method, and to demonstrate the excellent property of the new control method in application, several simulations are introduced. Finally, conclusions are given.

2. Description of the System

The schematic picture of a power generation system is shown in Figure 1, the control signal from dynamic controller to change the turbine generator valve, and the feed water flow, the goal of control is to make the pressure before turbine is almost constant, drum water level fluctuate at the desired value and satisfy the load requirement under any operation condition.

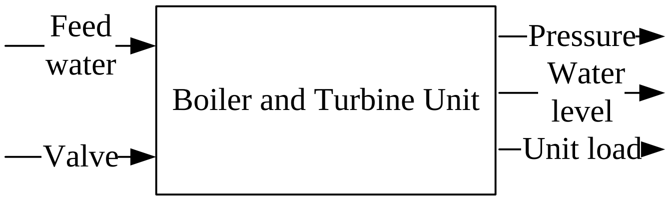

Figure 1. Control System Structure

The feed water, supplied to the drum and saturated steam is taken from the drum to the turbine. The steam amount is changed by the generator valve. The presence of the steam below the liquid level in the drum causes the shrink and swell phenomenon which makes level control difficult. The balance way of characterizing the system is convenient for modeling. For simulation and control it is necessary to account for the fact that mass flow rate depends on the pressure by modeling the turbine and the super-heaters. The dynamic model of power generation unit is given in Eq.1 [8].

$$\begin{cases} \ddot{p}_d = C_b \dot{p}_d - K_1 p_d + K_2 r_T + K_3 u_w \\ \ddot{l}_d = M_d \dot{l}_d - K_4 l_d + K_5 r_T + K_6 u_w \\ \dot{N}_E = -K_7 N_E + K_8 r_T \end{cases} \tag{1}$$

Where K_i, $i = 1, 2 \ldots 8$ denote the process parameter and time parameter of thermal power process, respectively. u_w and r_T denote the control command to satisfy the load in drum pressure and drum level, respectively. Δ_1 and Δ_2 denote uncertainties in this model State variables are defined as $x_1 = l_d$, $x_2 = \dot{l}_d$, $x_3 = r_B$, $x_4 = \dot{r}_B$, $x_5 = p_d$, $x_6 = \dot{p}_d$, $x_7 = r_m$, $x_8 = \dot{r}_m$, and. For the control goal is making the drum water level rate and pressure before rate be zero, in order to simplify the design process ,the hysteresis of the fire system are not considered in the design process. Treat the fuel of boiler a_B and load of turbine a_T as external disturbance of system. Then Eq.1 can be expressed as follows:

$$\begin{cases} \dot{x}_2 = -K_7 x_2 - x_1 - K_5 x_3 + a_{TB} \\ \dot{x}_3 = x_4 \\ \dot{x}_4 = -K_6 x_4 - x_3 + u_1 + \Delta_1 \\ \dot{x}_6 = -K_1 x_6 + K_3 x_2 x_6 + \dfrac{K_8 x_7}{R} - \dfrac{a_{T_\alpha}}{R} \\ \dot{x}_7 = x_8 \\ \dot{x}_8 = -M_d x_8 - K_4 x_7 + K_2 u_2 + \Delta_2 \end{cases} \tag{2}$$

3. Design of Dynamic Surface Controller

The dynamic surface control method proposed by Swaroop [12] was able to resolve the "explosion of terms" problem, which is caused by differential coefficient calculation in the model, and the problem can bring a complexity that will cause the usually method hardly to be applied to the practical applications, especially to the design of control law considering one-order dynamics of actuators-power.

In practical applications, the drum level and pressure control accuracy and the rapidity are not easy to obtain simultaneously, but their bounds can be known a priori. Assumed that $|a_{T\varepsilon}| < \varepsilon_1$, $|a_{T\beta}| < \varepsilon_2$, $|\Delta_1| < \rho_1$ and $|\Delta_2| < \rho_2$, where ε_1, ε_2, ρ_1 and ρ_2 are positive constant. Using dynamic surface control method, the guidance law accounting for second-order dynamics of missile autopilot is designed as follows.

3.1 Design of Water Control u_w

In order to make the stability of guidance system avoid the limit by the distance between the missile and the target, the *R* is added to the definition of first error-surface.

Step 1) Design a virtual control law for x_3.

The first error-surface is defined as

$$S_2 = x_2 - x_{2d} \tag{3}$$

And its derivative is

$$\dot{S}_2 = -x_2 - x_3 - x_6^2 x_1 - \dot{x}_{2d} + a_{T\varepsilon} \tag{4}$$

Choose a virtual control $\bar{x}_3$ to drive $S_2 \to 0$ as follows:

$$\bar{x}_3 = K_2 S_2 - x_2 - x_6^2 - x_{2d} - R\dot{x}_{2d} + a_{T\varepsilon} \tag{5}$$

Where x_{2d} is the desired value, K_2 is positive constant. Then, to obtain the filtering virtual control x_{3d}, pass $\bar{x}_3$ through a first-order filter with time constant $\tau_3 > 0$ as follows:

$$\tau_3 \dot{x}_{3d} + x_{3d} = \bar{x}_3,\quad x_{3d}(0) = \bar{x}_3(0) \tag{6}$$

Step 2) Design a virtual control law for x_4.

Define the second error-surface as

$$S_3 = x_3 - x_{3d} \tag{7}$$

And its derivative is

$$\dot{S}_3 = x_4 - \dot{x}_{3d} \tag{8}$$

Choose a virtual control $\bar{x}_4$ to drive $S_3 \to 0$ as follows:

$$\bar{x}_4 = -K_3 S_3 + \dot{x}_{3d} \tag{9}$$

Where K_3 is a positive constant. Then, to obtain the filtering virtual control x_{4d}, pass $\bar{x}_4$ through a first-order filter with time constant $\tau_4 > 0$ as follows:

$$\tau_4 \dot{x}_{4d} + x_{4d} = \bar{x}_4,\quad x_{4d}(0) = \bar{x}_4(0) \tag{10}$$

Step 3) Design the actual control u_1

Define the third error-surface as

$$S_4 = x_4 - x_{4d} \tag{11}$$

And its derivative is

$$\dot{S}_4 = -K_6 x_4 - x_3 + u_1 + \Delta_1 - \dot{x}_{4d} \tag{12}$$

Choose an actual control u_1 to drive $S_4 \to 0$ as follows:

$$\dot{S}_4 = -K_4 S_4 \tag{13}$$

In fact, it is hard to estimate the temperature change and load uncertainties, so function sign(.) are used to deal with temperature change and load uncertainties, then a practical new control is given as follows:

$$u_T = \frac{1}{\omega_n^2}\left[\frac{C_d K_2 - M_d}{\tau_3\tau_4}x_2 - \frac{K_2}{\tau_3\tau_4}x_{2d} + (\omega_n^2 - \frac{K_3}{\tau_4})x_3 + \frac{\tau_3 K_3 - 1}{\tau_3\tau_4}x_{3d} + K_4)x_4 + (K_4 - \frac{1}{\tau_4})x_{4d} - \frac{R}{\tau_3\tau_4}x_6^2 + \frac{\varepsilon_1 \operatorname{sgn} x_2}{\tau_3\tau_4} - \rho_1 \operatorname{sgn} x_2\right] \tag{14}$$

3.2 Design of Generator Valve r_T

The design of generator valve r_T is similar with it in feed-water control u_w , so the R is added to the definition of first error-surface in lateral plane. Considering the coupling existed between the pressure and level in heat exchanger process derived from Eq.2 and Eq.3, so the parameter is added to the definition of first error-surface in generator valve control

Define the first error-surface as

$$S_6 = R(x_6 - x_{6d}) \tag{15}$$

Where x_{6d} is desired value.

Define the second and third error-surface as

$$S_7 = x_7 - x_{7d} \tag{16}$$

$$S_8 = x_8 - x_{8d} \tag{17}$$

Where x_{7d} and x_{8d} are the filtering virtual control. The derivative of Eq.(15)~(17) are

$$\dot{S}_6 = +Rx_2x_6 + Rx_2x_{6d} - R\dot{x}_{6d} + x_7 - a_{T\beta} \tag{18}$$

$$\dot{S}_7 = x_8 - \dot{x}_{7d} \tag{19}$$

$$\dot{S}_8 = -2M_d x_8 - K_2 x_7 + u_2 + \Delta_2 - \dot{x}_{8d} \tag{20}$$

Choose virtual control $\bar{x}_i$ (i=7, 8) to drive $S_{i-1} \to 0$ as follows:

$$\bar{x}_7 = -K_6 S_6 - Rx_2x_6 - Rx_2x_{6d} + R\dot{x}_{6d} + a_{T\beta} \tag{21}$$

$$\bar{x}_8 = -K_7 S_7 + \dot{x}_{7d} \tag{22}$$

Where K_6 and K_7 are positive constant. Then, to obtain the filtering virtual control x_{id} (i=7, 8), pass $\bar{x}_i$ (i=7, 8) through first-order filters with time constant $\tau_i > 0$ (i=7, 8) as follows:

$$\tau_7 \dot{x}_{7d} + x_{7d} = \bar{x}_7 , \quad x_{7d}(0) = \bar{x}_7(0) \tag{23}$$

$$\tau_8 \dot{x}_{8d} + x_{8d} = \bar{x}_8 , \quad x_{8d}(0) = \bar{x}_8(0) \tag{24}$$

Choose an actual control u_2 to drive $S_8 \to 0$ as follows:

$$\dot{S}_8 = -K_8 S_8 \tag{25}$$

Similar as longitudinal plane, a practical new 3-D guidance law considering second-order dynamics of missile autopilot in lateral plane is given as follows:

$$r_T = \left[\frac{-RK_6}{\tau_7\tau_8}x_6 + \frac{R}{\tau_7\tau_8}\dot{x}_{6d} + (K_2 C_b - \frac{K_7}{\tau_8})x_7 + \frac{\tau_7 K_7 - 1}{\tau_7\tau_8}x_{7d} - K_8 x_8 + (K_8 - \frac{1}{\tau_8})x_{8d} - \frac{\varepsilon_2 \operatorname{sgn} x_6}{\tau_7\tau_8} - \rho_2 \operatorname{sgn} x_6\right] \tag{26}$$

If choose $K_3 = 1/\tau_3$, $K_4 = 1/\tau_4$, $K_7 = 1/\tau_7$ and $K_8 = 1/\tau_8$, then x_{3d} , x_{4d} , x_{7d} and x_{8d} are eliminated from Eq.(14) and Eq.(26). given $x_{2d} = 0$, $\dot{x}_{2d} = 0$, $x_{6d} = 0$ and $\dot{x}_{6d} = 0$. Then the control can be simplified as

$$u_1 = \left[\frac{RK_2}{\tau_3\tau_4}\dot{p}_d - \frac{C_b R}{\tau_3\tau_4}p_d^2 + -\frac{K_3}{\tau_4}l_d + K_4\dot{l}_d + \frac{1}{\tau_3\tau_4}\varepsilon_1 \operatorname{sgn} \dot{p}_d - \rho_1 \operatorname{sgn} \dot{p}_d \right] \tag{27}$$

$$u_2 = \left[\frac{-RK_6}{\tau_7\tau_8}x_6 + (K_2C_b - \frac{K_7}{\tau_8})x_7 + \frac{\tau_7K_7 - 1}{\tau_7\tau_8}x_{7d} - K_8x_8 + (K_8 - \frac{1}{\tau_8})x_{8d} - \frac{\varepsilon_2 \operatorname{sgn} x_6}{\tau_7\tau_8} - \rho_2 \operatorname{sgn} x_6 \right] \tag{28}$$

4. Analysis of System Stability

4.1. The Boundary Layer Errors in Control u_w

According to Eq.(6) and Eq.(10), define boundary layer errors as follows:

$$y_3 = x_{3d} - \overline{x}_3 = x_{3d} - K_2S_2 + \dot{R}x_2 + Rx_6^2 + \dot{R}x_{2d} + R\dot{x}_{2d} - a_{T\varepsilon} \tag{29}$$

$$y_4 = x_{4d} - \overline{x}_4 = x_{4d} + K_3S_3 - \dot{x}_{3d} \tag{30}$$

According to Eq.(3), Eq. (7), Eq.(11), Eq.(27) and Eq.(30), state variables can be rewritten as follows:

$$x_2 = S_2 / R + x_{2d} \tag{31}$$

$$\begin{aligned} x_3 = {} & S_3 + y_3 + K_2S_2 - \dot{R}x_2 - \\ & Rx_6^2 \sin x_1 \cos x_1 - \dot{R}x_{2d} - R\dot{x}_{2d} + a_{T\alpha} \end{aligned} \tag{32}$$

$$x_4 = S_4 + y_4 - K_3S_3 + \dot{x}_{3d} \tag{33}$$

The derivative of error-surface Eq.(4) and Eq.(8) can be rewritten as follows:

$$\dot{S}_2 = -S_3 - y_3 - K_2S_2 \tag{34}$$

$$\dot{S}_3 = S_4 + y_4 - K_3S_3 \tag{35}$$

Substituting the designed guidance law Eq.(14) into Eq.(12), get

$$\begin{aligned} \dot{S}_4 = {} & -K_4S_4 + (\varepsilon_1 \operatorname{sgn} x_2 - a_{T\varepsilon}) / (\tau_3\tau_4) + \\ & \omega_n^2(\Delta_1 - \rho_1 \operatorname{sgn} x_2) \end{aligned} \tag{36}$$

Differentiating Eq.(32), get

$$\dot{y}_3 = -\frac{y_3}{\tau_3} + \eta_3(S_2, S_3, y_3, K_2, x_{2d}, \dot{x}_{2d}, \ddot{x}_{2d}) \tag{37}$$

Where

$$\eta_3(S_2, S_3, y_3, K_2, x_{2d}, \dot{x}_{2d}, \ddot{x}_{2d}) = -K_2\dot{S}_2 + \ddot{R}x_2 + \dot{R}\dot{x}_2 + \dot{R}x_6^2x_1 + 2Rx_6\dot{x}_6 + Rx_6^2\dot{x}_1 + \ddot{R}x_{2d} + 2\dot{R}\dot{x}_{2d} + R\ddot{x}_{2d} - \dot{a}_{T\varepsilon} \tag{38}$$

Differentiating Eq.(30), get

$$\dot{y}_4 = -\frac{y_4}{\tau_4} + \eta_4(S_2, S_3, S_4, y_3, y_4, K_2, K_3, \tau_3, x_{2d}, \dot{x}_{2d}, \ddot{x}_{2d}) \tag{39}$$

Where

$$\eta_4(S_2, S_3, S_4, y_3, y_4, K_2, K_3, \tau_3, x_{2d}, \dot{x}_{2d}, \ddot{x}_{2d}) = K_3\dot{S}_3 - \ddot{x}_{3d} \tag{40}$$

4.2. The Boundary Layer Errors in Generator Valve r_T

According to Eq.(23) and Eq.(24), define boundary layer errors as follows:

$$y_7 = x_{7d} - \overline{x}_7 = x_{7d} + K_6S_6 + Rx_2(x_6 + x_{6d}) - (\dot{R}x_6 + R\dot{x}_{6d} + \dot{R}x_{6d})x_1 - a_{T\beta} \tag{41}$$

$$y_8 = x_{8d} - \overline{x}_8 = x_{8d} + K_7S_7 - \dot{x}_{7d} \tag{42}$$

According to Eq.(15)~Eq.(17), Eq.(41) and Eq.(42), state variables can be rewritten as follows:

$$x_6 = S_6 / (R\cos x_1) + x_{6d} \tag{43}$$

$$x_7 = S_7 + y_7 - K_6S_6 + \dot{R}x_6x_1 - Rx_2x_{61} - Rx_2x_{6d} + \dot{R}x_{6d} + R\dot{x}_{6d} + a_{T\beta} \tag{44}$$

$$x_8 = S_8 + y_8 - K_7S_7 + \dot{x}_{7d} \tag{45}$$

The derivative of error-surface Eq.(18) and Eq.(19) can be rewritten as follows:

$$\dot{S}_6 = S_7 + y_7 - K_6S_6 \tag{46}$$

$$\dot{S}_7 = S_8 + y_8 - K_7 S_7 \tag{47}$$

Substituting the designed guidance law Eq.(26) into Eq.(20), get

$$\dot{S}_8 = -K_8 S_8 + (-\varepsilon_2 \operatorname{sgn} x_6 - a_{T\beta}) / (\tau_7 \tau_8) + \omega_n^2 (\Delta_2 - \rho_2 \operatorname{sgn} x_6) \tag{48}$$

Differentiating Eq.(41), get

$$\dot{y}_7 = -\frac{y_7}{\tau_7} + \eta_7 (S_6, S_7, y_7, K_6, x_{6d}, \dot{x}_{6d}, \ddot{x}_{6d}) \tag{49}$$

Where

$$\eta_7 (S_6, S_7, y_7, K_6, x_{6d}, \dot{x}_{6d}, \ddot{x}_{6d}) = K_6 \dot{S}_6 + \left[\left(R x_2^2 - \ddot{R} \right) x_1 + \left(2 \dot{R} x_2 + R \dot{x}_2 \right) x_1 \right] (x_6 + x_{6d}) - \dot{a}_{T\beta} + \left(R x_2 - \dot{R} x_1 \right) (\dot{x}_6 + 2 \dot{x}_{6d}) - R \ddot{x}_{6d} \tag{50}$$

Differentiating Eq.(42), get

$$\dot{y}_8 = -\frac{y_8}{\tau_8} + \eta_8 (S_6, S_7, S_8, y_7, y_8, K_6, K_7, \tau_7, x_{6d}, \dot{x}_{6d}, \ddot{x}_{6d}) \tag{51}$$

Where

$$\eta_8 (S_6, S_7, S_8, y_7, y_8, K_6, K_7, \tau_7, x_{6d}, \dot{x}_{6d}, \ddot{x}_{6d}) = K_7 \dot{S}_7 - \ddot{x}_{7d} \tag{52}$$

4.3. The Verify of System Stability Based on Lyapunov Function

Define a Lyapunov function as follows:

$$V = \frac{1}{2} \left(S_2^2 + S_3^2 + S_4^2 + S_6^2 + S_7^2 + S_8^2 + y_3^2 + y_4^2 + y_7^2 + y_8^2 \right) \tag{53}$$

Its derivative is

$$\begin{aligned} \dot{V} = {} & S_2(-S_3 - y_3) + S_3(S_4 + y_4) + S_4 \frac{\varepsilon_1 \operatorname{sgn} x_2 - a_{T\varepsilon} + \tau_3 \tau_4 \omega_n^2 (\Delta_1 - \rho_1 \operatorname{sgn} x_2)}{\tau_3 \tau_4} + \\ & S_6(S_7 + y_7) + S_7(S_8 + y_8) + S_8 \frac{-\varepsilon_2 \operatorname{sgn} x_6 - a_{T\beta} + \tau_7 \tau_8 \omega_n^2 (\Delta_2 - \rho_2 \operatorname{sgn} x_6)}{\tau_7 \tau_8} - \\ & \sum_{i=2}^{4} K_i S_i^2 - \sum_{i=6}^{8} K_i S_i^2 - \sum_{i=3}^{4} \left(\frac{y_i^2}{\tau_i} - y_i \eta_i \right) - \sum_{i=7}^{8} \left(\frac{y_i^2}{\tau_i} - y_i \eta_i \right) \end{aligned} \tag{54}$$

For the desired value x_{2d} which is bounded, consider the set $Q = \left\{ (x_{2d}, \dot{x}_{2d}, \ddot{x}_{2d}) : x_{2d}^2 + \dot{x}_{2d}^2 + \ddot{x}_{2d}^2 \le K_0 \right\}$, $K_0 > 0$, clearly, Q is compact in R^3. For the sets $A_3 = \left\{ (S_2, S_3, y_3) : S_2^2 + S_3^2 + y_3^2 \le 2v^* \right\}$, $A_4 = \left\{ (S_2, S_3, S_4, y_3, y_4) : S_2^2 + S_3^2 + S_4^2 + y_3^2 + y_4^2 \le 2v^* \right\}$, $v^* > 0$, A_3 and A_4 are compact in R^3 and R^5, respectively. Moreover, $A_3 \times Q$ and $A_4 \times Q$ are compact in R^6 and R^8, respectively. Thus, η_3 and η_4 have maximum values on $A_3 \times Q$ and $A_4 \times Q$, respectively. then, there exist positive constants M_3 and M_4 such that $|\eta_3| \le M_3$ and $|\eta_4| \le M_4$. The same as that there exist positive constants M_7 and M_8 such that $|\eta_7| \le M_7$ and $|\eta_8| \le M_8$.

Set $\left| (\varepsilon_1 \operatorname{sgn} x_2 - a_{T\varepsilon}) / (\tau_3 \tau_4) + \omega_n^2 (\Delta_1 - \rho_1 \operatorname{sgn} x_2) \right| \le M_1$, and $\left| (-\varepsilon_2 \operatorname{sgn} x_6 - a_{T\beta}) / (\tau_7 \tau_8) + \omega_n^2 (\Delta_2 - \rho_2 \operatorname{sgn} x_6) \right| \le M_5$, where M_1 and M_5 are positive constants. Using Young's inequality, get

$$\begin{aligned} \dot{V} \le {} & |S_2|^2 + |S_3|^2/4 + |S_2|^2 + |y_3|^2/4 + |S_3|^2 + |S_4|^2/4 + |S_3|^2 + |y_4|^2/4 + |S_4|^2 + |M_1|^2/4 + |S_6|^2 + |S_7|^2/4 + \\ & |S_6|^2 + |y_7|^2/4 + |S_7|^2 + |S_8|^2/4 + |S_7|^2 + |y_8|^2/4 + |S_8|^2 + M_5^2/4 - \sum_{i=2}^{4} K_i S_i^2 - \sum_{i=6}^{8} K_i S_i^2 - \sum_{i=3}^{4} \frac{y_i^2}{\tau_i} - \sum_{i=7}^{8} \frac{y_i^2}{\tau_i} + \\ & |y_3|^2 + M_3^2/4 + |y_4|^2 + M_4^2/4 + |y_7|^2 + M_7^2/4 + |y_8|^2 + M_8^2/4 \end{aligned}$$

$$= (2 - K_2)S_2^2 + (9/4 - K_3)S_3^2 + (5/4 - K_4)S_4^2 + (2 - K_6)S_6^2 + (9/4 - K_7)S_7^2 + (5/4 - K_8)S_8^2 + (5/4 - 1/\tau_3)y_3^2 + (5/4 - 1/\tau_4)y_4^2 + (5/4 - 1/\tau_7)y_7^2 + (5/4 - 1/\tau_8)y_8^2 + \frac{1}{4}M_1^2 + \frac{1}{4}\sum_{i=3}^{5}M_i^2 + \frac{1}{4}M_7^2 + \frac{1}{4}M_8^2$$

Let

$$\begin{aligned} &K_2 = 2 + K_2^*, K_3 = 9/4 + K_3^*, K_4 = 5/4 + K_4^*, \\ &K_6 = 2 + K_6^*, K_7 = 9/4 + K_7^*, K_8 = 5/4 + K_8^*, \\ &1/\tau_3 = 5/4 + 1/\tau_3^*, 1/\tau_4 = 5/4 + 1/\tau_4^*, \\ &1/\tau_7 = 5/4 + 1/\tau_7^*, 1/\tau_8 = 5/4 + 1/\tau_8^* \end{aligned} \tag{55}$$

Where $K_2^*, K_3^*, K_4^*, \tau_3^*, \tau_4^*, K_6^*, K_7^*, K_8^*, \tau_7^*$ and τ_8^* are positive constants, then

$$\begin{aligned} \dot{V} &\le -\sum_{i=2}^{4} K_i^* S_i^2 - \sum_{i=6}^{8} K_i^* S_i^2 - \sum_{i=3}^{4}\frac{y_i^2}{\tau_i^*} - \sum_{i=7}^{8}\frac{y_i^2}{\tau_i^*} + \\ &\frac{1}{4}M_1^2 + \frac{1}{4}\sum_{i=3}^{5}M_i^2 + \frac{1}{4}M_7^2 + \frac{1}{4}M_8^2 \le -2\beta V + P \end{aligned} \tag{56}$$

Where

$$0 < \beta < \min(K_2^*, K_3^*, K_4^*, 1/\tau_3^*, 1/\tau_4^*, K_6^*, K_7^*, K_8^*, 1/\tau_7^*, 1/\tau_8^*),$$

$$P = M_1^2/4 + M_3^2/4 + M_4^2/4 + M_5^2/4 + M_7^2/4 + M_8^2/4 .$$

Equation (56) implies that $\dot{V} < 0$ when $\beta > P/(2v^*)$. Therefore, $V \le v^*$ is an invariant set, this implies that if $V(0) \le v^*$, then $V(t) \le v^*$ for all $t > 0$. Thus, S_2, S_3, S_4, S_6, S_7, S_8, y_3, y_4, y_7 and y_8 are all uniformly ultimately bounded. If large enough K_i (*i*=2～4, 6～8) and small enough τ_i (*i*=3, 4, 7, 8) are chosen, then β is large enough and $P/(2\beta)$ is small enough. It means that the state bounded range is small enough, *i.e.*, S_2, S_3, S_4, $S_6, S_7, S_8, y_3, y_4, y_7$ and y_8 can be made arbitrarily small ultimately through properly adjusting design parameters, the stabilization of control system is guaranteed.

The above process of stability analysis is still available according to the simplified drum level and pressure system.

5. Simulation Results

Herein, we use a model that gives a good description of the boiler including the drum level. The third-order model captures the steam dynamics in the risers and also describes the dynamics of steam below the water surface in the drum. The third equation is a combination of mass and energy balances for the rise and steam under the water level in the drum. The parameters used in this paper were based on construction data and experiments. Some of them were quite crude through a comprehensive investigation. The results showed that drum pressure and level dynamics can be achieved significantly by identification methods. Significant improvements can also be obtained by adjusting the coefficients in the calibration formula for the sensors. Parameters of drum volume, riser volume, down comer volume, drum area at normal operating level, total metal mass , total riser mass, friction coefficient in down comer-riser loop ,residence time of steam in drum, parameter bare got from provider manual.

The simulation step is 0.01s, the missile's maximum permitting overload is 20, according to the demand of thermal power generation operation and practice engineering experience, dynamic parameters are chosen under 100% load. The uncertainties of missile autopilot is set to be $\Delta_1 = 8\sin t$ m/s2 and $\Delta_2 = 8\sin t$ m/s2, it is simulated for maneuvering target. To illustrate the dynamic behavior of the control methods we will compare the result with the responses of PID controls. Since there are many inputs and many interesting characters we will focus on a few selected point views. One input was changed and the others were kept constant. The magnitudes of the changes were about 10% of the nominal values of the signals. To compare responses at same load conditions adopting different control methods.

The design parameters of the new control methods are chosen as $\varepsilon_1 = 650$, $\varepsilon_2 = 650$, $\rho_1 = 10$, $\rho_2 = 10$, $K_2^* = 1$, $K_3^* = 31/4$, $K_4^* = 195/4$, $K_6^* = 1$, $K_7^* = 31/4$, $K_8^* = 195/4$, $\tau_3^* = 4/35$, $\tau_4^* = 4/195$, $\tau_7^* = 4/35$ and $\tau_8^* = 4/195$. It can be obtained from Eq.(55) that $K_2 = 3$, $K_3 = 10$, $K_4 = 50$, $K_6 = 3$, $K_7 = 10$, $K_8 = 50$, $\tau_3 = 0.1$, $\tau_4 = 0.02$, $\tau_7 = 0.1$ and $\tau_8 = 0.02$.

To demonstrate the validity of control strategy based dynamic surface methods, we compare the system response curves with conventional PID control method with novel control method given in this paper under 100%load respectively.

Dynamical properties of the closed loop with PID controlled system, which is designed based conventional engineering tuning methods, are considerably worse than dynamic properties of the closed loop with dynamic surface control system. The former stabilizes slower and has larger surplus oscillations. Moreover the closed loop with the new dynamic surface controlled system is more sensitive to the changes in the controller parameters. At the beginning of the process, PID controlled system response more quickly to disturbance of load than the other one. Two figures show the response curve changes distinctly when the load changes of the two different control methods .Under lower load condition, the closed loop properties of the both control strategies deteriorate, while the quality of new DS control loop is better than PID control loop in rapidity stability and accuracy.

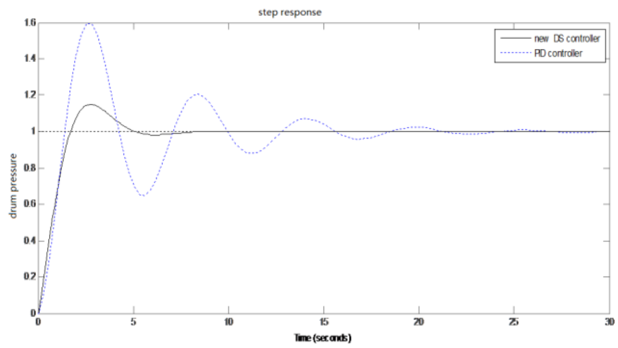

Figure 1. Step Response Curve for Drum Pressure

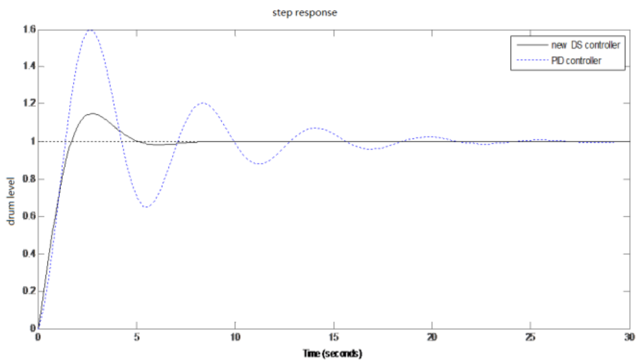

Figure 2. Step Response Curve for Drum Level

The variations of load make the dynamical character change severely. If the parameters of controller PID don not change correspondently, rapidity and stability of the closed loop are hardly to satisfy the continuous industry process requirement. From Figures the new dynamic surface control method with state observer has satisfactory performance in dynamical and stable process, which can ensure the power unit work steadily under different load, fast response and track load .Therefore the new control method based dynamic surface is stable and effective.

6. Conclusion

In this paper, the new control method accounting for two important parameters of drum in thermal power generation is designed using dynamic surface control method. The new control method need to know the state space of the continuous process, and the dynamic structure is constructed from operation data and provider manual. So this is a practical control method overcoming the bad effect causing by temperature noise. The simulation results illustrate the new control method ensures an accurate, stable and fast load track, even if the load change in a great and it shows this new control strategy is effective, practicable and superior to conventional PID control.

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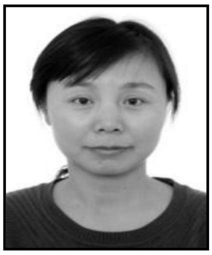

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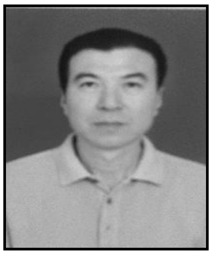

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