

Steam Temperature Control Basing On Dynamic Surface Control Method

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Abstract

A novel steam temperature control method is developed using the dynamic surface control method in this paper which is based on the saturated water-steam temperature system states observer and the one-order dynamics of the experiment for sprayer element. 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: *Steam Temperature, Dynamic Surface Control, Third-Order Dynamics*

1. Introduction

The continuous process in the heat exchanger is a complex system characterized by nonlinearity, uncertainty and load disturbance. The steam generating from water by burning fuel is used to generate electricity in one or more turbines. The control of steam temperature is critical in operations of utility boilers. It is important that the temperature of steam existing from a boiler and entering a steam turbine is at an optimally desired value. If the steam temperature is too high, it may cause damage to the blades of the steam turbine for various metallurgical reasons. If the steam temperature is too low, it may contain water particles which may cause damage to components of the steam turbine. Typically, a boiler contains cascaded heat exchanger sections where the steam existing from one heat exchanger section with the temperature increasing at each heat exchanger section until the steam is output to the turbine at the desired steam temperature. In such systems, the control of the steam is often achieved by spraying saturated water in to the steam at a point before the final heat exchanger section.

The main steam temperature control system is necessary to ensure high efficiency and high load-following capability in the operation of modern power plant, which has the characteristics of large inertia, large time-delay and time-varying, etc. Thus conventional PID control strategy cannot achieve good control performance. Presently, engineers and technicians adopt some new control methods, such as advanced PID algorithms, Fuzzy control methods, neural network and etc. to solve the steam temperature control problems. 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 steam temperature in the paper [2]; A composite control strategy based

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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.

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 Backstepping 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 filter technique, which overcomes the problems of 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 spraying water-steam temperature. In this system, controlled variable is steam temperature of super-heater exit, control variable is the saturated water. Firstly, two-order dynamic surface method needs three variable, and the global state observer is constructed for the application. Secondly, temperature controller is designed adopting dynamic surface control method, avoiding the occurrence of high-order derivatives of the spraying water 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.

1.1. Description of the System

The sprayer and superheater steam generation process is illustrated in Figure 1, and the control signal from controller to change the electrical valve, and the volume flow is changed into steam, the goal of control is to make the steam temperature fluctuate at the desired value under the condition with any power unit load.

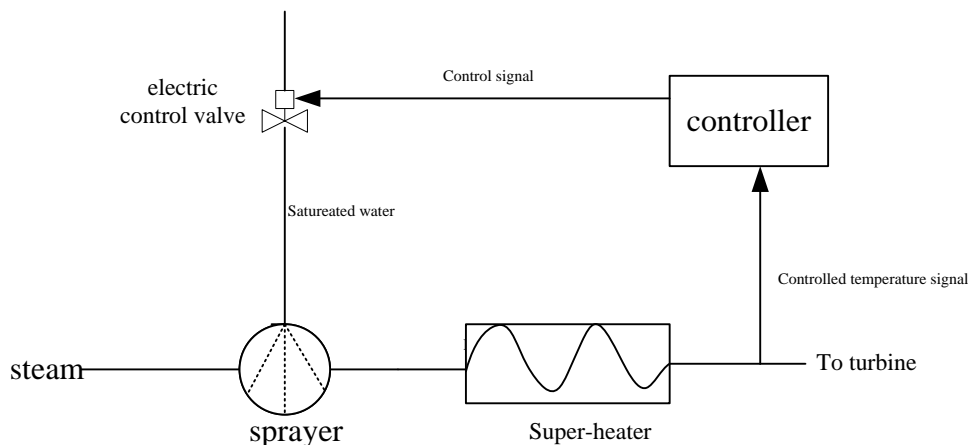


Figure 1. Control System Structure

The mathematical model of saturated water-steam temperature transfer function is given in Equation(1), where Y is steam temperature, X is volume flow of saturated water from sprayer to steam. In the transfer function P is steam mass

flow related to load, $c_p, \tau_0, T_m, \alpha_D$ are parameters related to structure of components invariantly .In practice, there parameters have obviously effect on the characteristic of the process.

$$W_G = \frac{Y}{X} = \frac{k}{P c_p (1 + 0.5(\tau_0 + T_m \alpha_D s))} \quad (1)$$

The former mathematic model was built neglecting the dynamic of the valve of sprayer, so this paper rebuilds the mathematic model of saturated water-steam temperature with the respect to the dynamic of the valve .The transfer function simple is given by fitting lab data that can be expressed as follows:

$$W = \frac{K}{(1 + T_0 S)^3} \quad (2)$$

To simplify the design process using dynamic surface method, it is transferred into state equations in Equation (3) :

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx \end{cases} \quad (3)$$

Where

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}; A = \begin{bmatrix} -\frac{1}{T_0} & \frac{1}{T_0} & 0 \\ 0 & -\frac{1}{T_0} & \frac{1}{T_0} \\ 0 & 0 & -\frac{1}{T_0} \end{bmatrix}; B = \begin{bmatrix} 0 \\ 0 \\ K_0/T_0 \end{bmatrix}; C = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \quad (4)$$

Parameters in equation (3) are substituted by $a = 1/T_0$, $b = K_0/T_0$;State variables are defined as $[x_1 \ x_2 \ x_3]^T$,The Equation (2) is written in the form of

$$\begin{cases} \dot{x}_1 = ax_2 - ax_1 \\ \dot{x}_2 = ax_3 - ax_2, y = x_1, \\ \dot{x}_3 = bu - ax_3 \end{cases} \quad (5)$$

Output $y = x_1$ is the steam temperature, x_2 and x_3 have no obvious physical meaning that are got by state prediction ,and control input is the control signal to sprayer deciding amount of saturated waters praying into the steam. The goal of control is to design a dynamic surface controller to make the steam temperature tracking the desired value x_{1d} quickly in economy.

1.2. State Observer

In the Equation(3), x_1 is the steam temperature that is measured by three sets of thermocouples .while state variable x_2 and x_3 are not physical quantity, it impossible to get the values of state variable x_2 and x_3 , using common

measurement instrument and methods. For completing the dynamic surface controller design, we construct state observer and get the value that have no obvious physical meaning by state prediction.

Pole - placement technique is employed to integrate the states, choose parameter $K=[K_1 \ K_2 \ K_3]^T$, define $A_0=A-KC$, where A_0 satisfy Hurwitz polynomial.

The state-space observer is designed as follows:

$$\begin{cases} \dot{\hat{x}} = A\hat{x} + Bu + K(y - \hat{y}) \\ \hat{y} = C\hat{x} \end{cases} \quad (6)$$

Where \tilde{x} is observation error of state vector,

$$\tilde{x} = x - \hat{x} \quad (7)$$

Then derivate the Equation (7), we get Equation (8)

$$\dot{\tilde{x}} = \dot{x} - \dot{\hat{x}} = A_0\tilde{x} \quad (8)$$

Because A_0 satisfy Hurwitz matrix, \tilde{x} is decaying exponentially to 0, and the inequality $\dot{\tilde{x}}_i^2 \leq \tilde{x}_i^2(0)$ is satisfied. The Equation (6) is written in components as follows:

$$\begin{cases} \dot{\hat{x}}_1 = a\hat{x}_2 - a\hat{x}_1 + K_1(x_1 - \hat{x}_1) \\ \dot{\hat{x}}_2 = a\hat{x}_3 - a\hat{x}_2 + K_2(x_1 - \hat{x}_1) \\ \dot{\hat{x}}_3 = bu - a\hat{x}_3 + K_3(x_1 - \hat{x}_1) \end{cases} \quad (9)$$

2. 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 for superheater steam system.

In practical applications, the temperature control accuracy and the rapidity are not easy to obtain simultaneously, but their bounds can be known a priori. Using dynamic surface control method, controller is designed as follows.

In order to make the stability of control system avoid the limit by the main steam flow P, the P is added to the definition of first error-surface.

Step 1) Design a virtual control law for x_2 .

The first error-surface is defined as

$$S_1 = P(x_1 - x_{1d}) \quad (10)$$

x_{1d} is desired value and Equation (10)its derivative is

$$\dot{S}_1 = -(\dot{P} + Pa)x_1 - \dot{P}x_{1d} - P\dot{x}_{1d} + Pa(\hat{x}_2 + \tilde{x}_2) \quad (11)$$

Choose a virtual control \bar{x}_2 to drive $S_1 \rightarrow 0$ as follows:

$$\bar{x}_2 = \frac{1}{Pa}(C_1S_1 + (\dot{P} + Pa)x_1 + \dot{P}x_{1d} + P\dot{x}_{1d}) \quad (12)$$

where x_{1d} is the desired value, C_1 is positive constant. Then, to obtain the filtering virtual control x_{2d} , pass \bar{x}_2 through a first-order filter with time constant $\tau_2 > 0$ as follows:

$$\tau_2 \dot{x}_{2d} + x_{2d} = \bar{x}_2 \quad x_{2d}(0) = \bar{x}_2(0) \quad (13)$$

Step 2) Design a virtual control law for x_3 .

Define the second error-surface as

$$S_2 = \hat{x}_2 - x_{2d} \quad (14)$$

And derivate Equation (14) ,its derivative is

$$\dot{S}_2 = \dot{\hat{x}}_2 - \dot{x}_{2d} = a\hat{x}_3 - a\hat{x}_2 + C_2(x_1 - \hat{x}_1) - \dot{x}_{2d} \quad (15)$$

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

$$\bar{x}_3 = \frac{1}{a}(C_2 S_2 + a\hat{x}_2 - C_2(x_1 - \hat{x}_1) + \dot{x}_{2d}) \quad (16)$$

where C_2 is a 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:

$$\tau_3 \dot{x}_{3d} + x_{3d} = \bar{x}_3 \quad x_{3d}(0) = \bar{x}_3(0) \quad (17)$$

Step 3) Design the actual control u

Define the third error-surface as

$$S_3 = \hat{x}_3 - x_{3d} \quad (18)$$

and its derivative is

$$\dot{S}_3 = bu - a\hat{x}_3 + K_3(x_1 - \hat{x}_1) - \dot{x}_{3d} \quad (19)$$

Choose an actual control u to drive $S_3 \rightarrow 0$ as follows:

$$\dot{S}_3 = -C_3 S_3 \quad (20)$$

The control is achieved as followings: using Equation (19) and Equation (20), we get Equation (21)

$$\begin{aligned} -C_3 S_3 &= bu - a\hat{x}_3 + K_3(x_1 - \hat{x}_1) - \dot{x}_{3d} \\ -C_3(\hat{x}_3 - x_{3d}) &= bu - a\hat{x}_3 + K_3(x_1 - \hat{x}_1) - \dot{x}_{3d} \\ bu &= (-C_3 + a)\hat{x}_3 + C_3 x_{3d} + a\hat{x}_3 - K_3(x_1 - \hat{x}_1) + \dot{x}_{3d} \end{aligned} \quad (21)$$

Substitute parameters by Equation (17) and (18), and Equation (22) is obtained

$$\begin{aligned} bu &= (-C_3 + a)\hat{x}_3 + C_3 x_{3d} + a\hat{x}_3 - K_3(x_1 - \hat{x}_1) + \frac{\bar{x}_3 - x_{3d}}{\tau_3} \\ \bar{x}_3 &= \frac{1}{a}(C_2 S_2 + a\hat{x}_2 - K_2(x_1 - \hat{x}_1) + \dot{x}_{2d}) \end{aligned} \quad (22)$$

$$bu = (-C_3 + 2a)\hat{x}_3 + (C_3 - \frac{1}{\tau_3})x_{3d} - K_3(x_1 - \hat{x}_1) + \frac{1}{a\tau_3}(C_2 S_2 + a\hat{x}_2 - K_2(x_1 - \hat{x}_1) + \dot{x}_{2d})$$

Deal the equations repeatedly, and Equation (23) is obtained

$$\begin{aligned} bu &= [(C_3 - a)\hat{x}_3 + (C_3 - \frac{1}{\tau_3})x_{3d} + (a + \frac{C_2}{\tau_3})\hat{x}_2 - (\frac{C_2}{a\tau_3} + \frac{C_2}{a\tau_3\tau_2})x_{2d} + \frac{C_2}{a^2\tau_3\tau_2}(C_1 + 1 + a)x_1 + \\ &\quad \frac{C_2}{Pa^2\tau_3\tau_2}(\dot{P} - C_1 P)x_{1d} + \frac{C_2}{a^2\tau_3\tau_2}\dot{x}_{1d}] \end{aligned} \quad (23)$$

Completing above work, we get the control function to satisfy the requirement expressed in Equation (24)

$$u = \frac{1}{b} \left[\begin{aligned} & (C_3 - a)\hat{x}_3 + (C_3 - \frac{1}{\tau_3})x_{3d} + (a + \frac{C_2}{a\tau_3})\hat{x}_2 - (\frac{C_2}{a\tau_3} + \frac{C_2}{a\tau_3\tau_2})x_{2d} + \\ & \frac{C_2}{a^2\tau_3\tau_2}(C_1 + 1 + a)x_1 + \frac{C_2}{Pa^2\tau_3\tau_2}(\dot{P} - C_1P)x_{1d} + \frac{C_2}{a^2\tau_3\tau_2}\dot{x}_{1d} \end{aligned} \right] \quad (24)$$

In fact, it is hard to estimate the flow disturbance and load uncertainties, so function $\text{sgn}(\cdot)$ are used to deal with system components uncertainties, then a practical new control law considering system uncertainties is given in Equation (25) as follows:

$$u = \frac{1}{b} \left[\begin{aligned} & (C_3 - a)\hat{x}_3 + (C_3 - \frac{1}{\tau_3})x_{3d} + (a + \frac{C_2}{a\tau_3})\hat{x}_2 - (\frac{C_2}{a\tau_3} + \frac{C_2}{a\tau_3\tau_2})x_{2d} + \\ & \frac{C_2}{a^2\tau_3\tau_2}(C_1 + 1 + a)x_1 + \frac{C_2}{Pa^2\tau_3\tau_2}(\dot{P} - C_1P)x_{1d} + \frac{C_2}{a^2\tau_3\tau_2}\dot{x}_{1d} + \frac{\varepsilon_1 \text{sgn } x_1}{\tau_3\tau_2} \end{aligned} \right] \quad (25)$$

3. Analysis of System Stability

3.1. Boundary Layer Error

According to Equation (13) and Equation (17), boundary layer errors are defined in Equation (26) and (27) as follows:

$$y_2 = x_{2d} - \bar{x}_2 = x_{2d} - \frac{1}{Pa}(C_1S_1 + (\dot{P} + Pa)x_1 + \dot{P}x_{1d} + P\dot{x}_{1d}) \quad (26)$$

$$y_3 = x_{3d} - \bar{x}_3 = x_{3d} - \frac{1}{a}(C_2S_2 + a\hat{x}_2 - K_2(x_1 - \hat{x}_1) + \dot{x}_{2d}) \quad (27)$$

According to Equation (10), Equation (14), Equation (26) and Equation (27), state variables can be rewritten as follows:

$$x_1 = S_1/P + x_{1d} \quad (28)$$

$$x_2 = S_2 + y_2 + \frac{1}{Pa}(C_1S_1 + (\dot{P} + Pa)x_1 + \dot{P}x_{1d} + P\dot{x}_{1d}) \quad (29)$$

$$x_3 = S_3 + y_3 + \frac{1}{a}(C_2S_2 + a\hat{x}_2 - K_2(x_1 - \hat{x}_1) + \dot{x}_{2d}) \quad (30)$$

The derivative of error-surface Equation (11) and Equation (15) can be rewritten as follows:

$$\begin{aligned} \dot{S}_1 &= -(\dot{P} + Pa)x_1 - \dot{P}x_{1d} - Pa\bar{x}_2 + C_1S_1 + (\dot{P} + Pa)x_1 + \dot{P}x_{1d} + Pa(\hat{x}_2 + \tilde{x}_2) \\ \dot{S}_1 &= -Pa\bar{x} + C_1S_1 + Pa(S_2 + y_2 + \tilde{x}_2) \\ \dot{S}_1 &= PaS_2 + C_1S_1 + -Pa\bar{x} + Pay_2 + Pa\tilde{x}_2 \end{aligned} \quad (31)$$

$$\begin{aligned} \dot{S}_2 &= \dot{\hat{x}}_2 - \dot{x}_{2d} = a\hat{x}_3 - a\hat{x}_2 + K_2(x_1 - \hat{x}_1) - \dot{x}_{2d} \\ \dot{S}_2 &= \dot{\hat{x}}_2 - \dot{x}_{2d} = a(S_3 + x_{3d}) - a\hat{x}_2 + K_2(x_1 - \hat{x}_1) - \dot{x}_{2d} \\ \dot{S}_2 &= \dot{\hat{x}}_2 - \dot{x}_{2d} = a(S_3 + y_3 + \bar{x}_3) - a\hat{x}_2 + K_2(x_1 - \hat{x}_1) - \dot{x}_{2d} \\ \dot{S}_2 &= \dot{\hat{x}}_2 - \dot{x}_{2d} = aS_3 + C_2S_2 + ay_3 \end{aligned} \quad (32)$$

Substituting the designed control law Equation (25) into Equation (19), get

$$\dot{S}_3 = -C_3S_3 \quad (33)$$

Differentiating Equation (26), get

$$\dot{y}_2 = -y_2/\tau_2 + \eta_2(S_1, S_2, y_2, K_1, x_{1d}, \dot{x}_{1d}, \ddot{x}_{1d}) \quad (34)$$

where

$$\eta_2(S_1, S_2, y_2, K_1, x_{1d}, \dot{x}_{1d}, \ddot{x}_{1d}) = -C_1 \dot{S}_1 + \ddot{P}x_1 + \dot{P}\dot{x}_1 + \ddot{P}x_{1d} + 2\dot{P}\dot{x}_{1d} + P\ddot{x}_{1d} \quad (35)$$

Differentiating Equation(27), get

$$\dot{y}_3 = -y_3/\tau_3 + \eta_3(S_1, S_2, S_3, y_2, y_3, C_1, C_2, \tau_2, x_{1d}, \dot{x}_{1d}, \ddot{x}_{1d}) \quad (36)$$

where

$$\eta_3(S_1, S_2, S_3, y_2, y_3, C_1, C_2, \tau_2, x_{1d}, \dot{x}_{1d}, \ddot{x}_{1d}) = C_2 \dot{S}_2 + \dot{y}_2/\tau_2$$

3.2. The Verify of System Stability Based on Lyapunov Function

Define a Lyapunov function as follows:

$$V = (S_1^2 + S_2^2 + S_3^2 + y_2^2 + y_3^2)/2 \quad (37)$$

Its derivative is

$$\dot{V} = S_1(-S_2 - y_2) + S_2(S_3 + y_3) + S_3 \frac{\varepsilon_1 \operatorname{sgn} x_1}{\tau_2 \tau_3} - C_1 S_1^2 - C_2 S_2^2 - C_3 S_3^2 - y_2^2/\tau_2 - y_3^2/\tau_3 + y_2 \eta_2 + y_3 \eta_3 \quad (38)$$

For the desired value x_{1d} which is bounded, consider the set $Q = \{(x_{1d}, \dot{x}_{1d}, \ddot{x}_{1d}) : x_{1d}^2 + \dot{x}_{1d}^2 + \ddot{x}_{1d}^2 \leq C_0\}$, $K_0 > 0$, clearly, Q is compact in R^3 . For the sets $A_2 = \{S_1^2 + S_2^2 + y_2^2 \leq 2v^*\}$, $A_3 = \{S_1^2 + S_2^2 + S_3^2 + y_2^2 + y_3^2 \leq 2v^*\}$, $v^* > 0$, A_2 and A_3 are compact in R^3 and R^5 , respectively. Thus, η_2 and η_3 have maximum values on $A_2 \times Q$ and $A_3 \times Q$, respectively. then, there exist positive constants M_2 and M_3 such that $|\eta_2| \leq M_2$ and $|\eta_3| \leq M_3$. Set $|(\varepsilon_1 \operatorname{sgn} x_1 / (\tau_2 \tau_3))| \leq M_1$, where M_1 , M_2 and M_3 are positive constants. Using Young's inequality, get

$$\dot{V} \leq |S_1|^2 + |S_2|^2/4 + |S_1|^2 + |y_2|^2/4 + |S_2|^2 + |S_3|^2/4 + |S_2|^2 + |y_3|^2/4 + |S_3|^2 + \quad (39)$$

$$M_1^2/4 - C_1 S_1^2 - C_2 S_2^2 - C_3 S_3^2 - y_2^2/\tau_2 - y_3^2/\tau_3 + |y_2|^2 + M_2^2/4 + |y_3|^2 + M_3^2/4 \quad (40)$$

Let

$$C_1 = 2 + C_1^*, C_2 = 9/4 + C_2^* \quad (41)$$

$$C_3 = 5/4 + C_3^*, 1/\tau_2 = 5/4 + 1/\tau_2^*$$

$$1/\tau_3 = 5/4 + 1/\tau_3^*$$

$$\dot{V} \leq -\sum_{i=1}^3 K_i^* S_i^2 - \sum_{i=1}^2 y_{i+1}^2/\tau_{i+1}^* + M_1^2/4 + M_2^2/4 + M_3^2/4 \leq -2\beta V + P \quad (42)$$

where $C_1^*, C_2^*, C_3^*, \tau_2^*$ and τ_3^* are positive constants, then

$$\dot{V} \leq -\sum_{i=1}^3 K_i^* S_i^2 - \sum_{i=1}^2 y_{i+1}^2/\tau_{i+1}^* + M_1^2/4 + M_2^2/4 + M_3^2/4 \leq -2\beta V + P \quad (43)$$

where $0 < \beta < \min[C_1^*, C_2^*, C_3^*, 1/\tau_2^*, 1/\tau_3^*]$, and $P = M_1^2/4 + M_2^2/4 + M_3^2/4$.

Equation (42) implies that $\dot{V} < 0$ when $\beta > P/(2v^*)$. Therefore, $V \leq v^*$ is an invariant set, this implies that if $V(0) \leq v^*$, then $V(t) \leq v^*$ for all $t > 0$. Thus, error-surface S_1, S_2, S_3 ; layer errors y_2 and y_3 are all uniformly ultimately bounded. If large enough C_i ($i=1 \sim 3$) and small enough τ_i ($i=2,3$) are chosen, then β is large enough and $P/(2\beta)$ is small enough. It means that the state bounded range is small enough, S_1, S_2, S_3, y_2 and

y_3 can be made arbitrarily small ultimately through properly adjusting design parameters, the stabilization of temperature control system is guaranteed.

4. Simulation Results

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%, 50% and 37% load respectively.

For example, from table1 under condition of 100% load , transfer function Equation (44) by fitting experiment data .

$$W = \frac{0.815}{(1+18s)^3} \quad (44)$$

Table 1. Spray Water-Steam Temperature under Different Load

load	Transfer function
37%	$\frac{5.072}{(1+35s)^3}$
50%	$\frac{3.067}{(1+25s)^3}$
100%	$\frac{0.815}{(1+18s)^3}$

Chang transfer function to state equation, we get

$$A_{100} = \begin{bmatrix} -0.056 & 0.056 & 0 \\ 0 & -0.056 & 0.056 \\ 0 & 0 & -0.056 \end{bmatrix}; B_{100} = \begin{bmatrix} 0 \\ 0 \\ 0.045 \end{bmatrix}; C_{100} = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

We get observer parameter $K_{100} = [0.78 \ 1.43 \ 0.21]^T$, controller parameters are selected as following, $C_1^* = 1$, $C_2^* = 31/4$, $C_3^* = 35/4$, $\tau_2^* = 4/35$, $\tau_3^* = 4/35$, from equation(41), we get $C_1 = 3$, $C_2 = 10$, $C_3 = 10$, $\tau_2 = 0.1$, $\tau_3 = 0.1$, and $V = 1/\tau_2$, assume desired signal of steam temperature x_{1d} is unit step signal. A comparison of the unit-step response of the closed-loop PID control and new dynamic control are shown in **Figure 2,3** and **4**, where the solid lines are simulation curves of novel dynamic surface (DS) control, and the dotted lines are the simulation curves of conventional PID control.

Table 2. Conventional PID Controller Parameters

load	Conventional PID controller		
	Proportional band	Integral time	Derivative time
37%	0.88	353.95	88.5
50%	0.85	240.5	60.1
100%	0.83	94.8	23.7

Figure 2 shows 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.

Complete the steps like the former one, the simulation result is give in the following Figure 3, which shows under the condition of 50% load the closed loop with the same parameters of new DS controller for 100% responses more quickly and requires less adjusting time with almost equal overshoot .This improvement is obtained by the state observer.

Figure 4 shows 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.

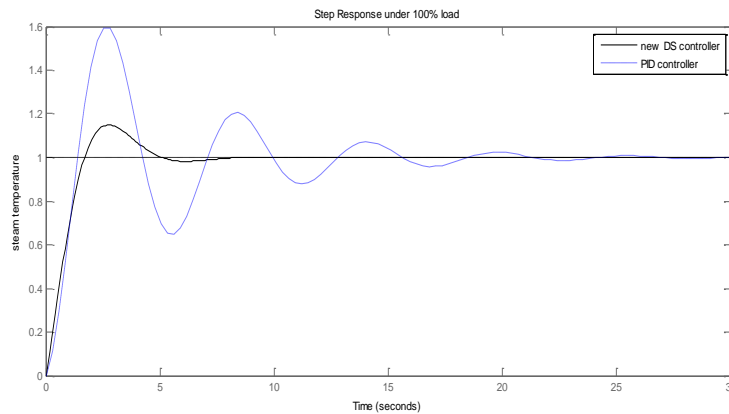


Figure 2. Step Response Curve Under 100% Load

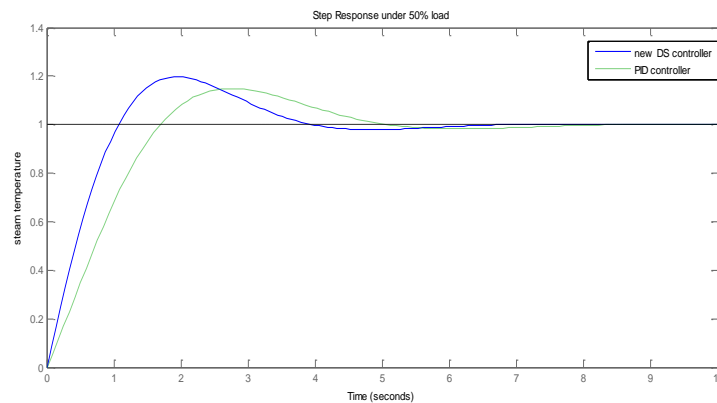


Figure 3. Step Response Curve Under 50% Load

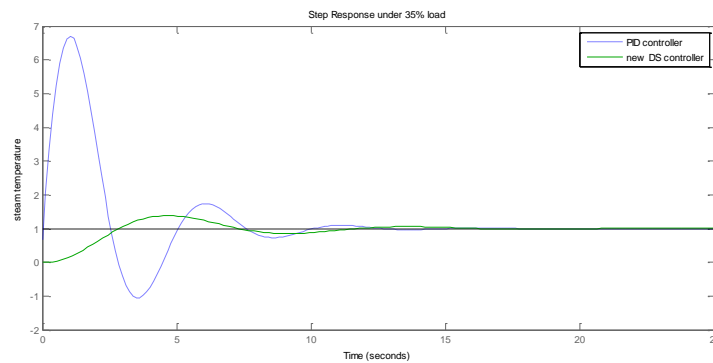


Figure 4. Step Response Curve Under 35% Load

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 2-3, 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

5. Conclusion

In this paper, the new control method accounting for dynamics of first order actuator is designed using dynamic surface control method. The new control method need to know the state space of the continuous process , and the state observer is constructed based on pole-placement method for that . So this is a practical control method overcoming the bad effect causing by first-order dynamics of sprayer valve. 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.

Acknowledgments

This work was supported in part by the Program for Excellent Talents of Shenyang Engineering Institute (LGYB-1102) , Program of Liaoning Provincial Office of Education (L2014526) and the National Natural Science Foundation of China (*****).

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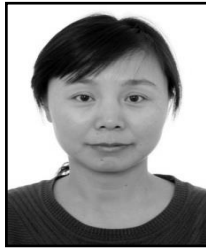
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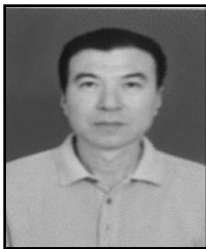
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