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Fuzzy adaptive control for boiler based on nonlinear depth recursion[1]

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Abstract. Fuzzy adaptive control for boiler (FACB) is a kind of boiler data drive control method, which has advantages of simple calculation, strong robustness and no modeling. At present, the fuzzy adaptive control methods for boiler generally do not take the non-linear control problem of the boiler that may occur into consideration. In view of this paper, an improved algorithm is designed in this paper for the situation that the upper limit of the actuator execution capability. The algorithm uses the nonlinear depth recursive method to solve the problem by introducing the constraint condition to the depth recursion, with the advantages of simple programming and small computation amount. On the basis, the closed-loop stability is analyzed and proved. Finally, the effectiveness of the algorithm is verified by comparing the simulation experiment with the boiler as the control object.

Key words. Fuzzy adaptive control for boiler, boiler nonlinear control, robustness, boiler data drive.

1. Introduction

Since the 1950s, the model-based control theory has been developed and perfected rapidly. The process of establishing the control system has gone through three stages, followed by the establishment of the model, the analysis of the model and the design of the control law by the model [1]. However, with the controlled object becoming more and more complex, how to model the controlled object effectively has become increasingly difficult. The reason lies in that for a system, if the constructed mathematical model is too complex, it will be difficult to design the control law or hard to implement the control law obtained in the engineering [2–3]. While if it is too simple, it will be difficult to reflect the dynamic characteristics of the actual system, thus the control law designed based on this model will be hard to achieve the desired control effect in the practical application. Secondly, the main methods

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for the establishment of the system model include the mechanism modeling and system identification. No matter which method is sued, the model established is the approximation to the real system, while the actual system will inevitably have the impact on the unmodeled dynamic of the control system robustness and other uncertain factors [4–5].

At present, there are two main methods to solve the above problem. The first category of methods is based on the boiler data drive control method. Currently there are three typical methods including the virtual reference feedback tuning (VRFT), synchronous disturbance random (SPSA) and fuzzy adaptive control for boiler (FACB). VRFT was proposed by Guardabassi et al. in 2000, which is characterized by the design of control law based on off-line data. The method is based on the model reference adaptive, and the controller parameters are obtained directly by the parameter identification, so that the dynamic characteristics of the closed-loop system are approximated to the reference model [6]. As the dynamic information of the actual system cannot be fully obtained by one excitation, the controller obtained by using the method design is difficult to ensure the stability of the closed-loop system. SPSA was proposed by Spall in 1993, which is characterized by iterative identification of system parameters, the control effect is susceptible to changes in system structure or parameter changes. It is difficult to guarantee the stability of closed-loop system [7]. FACB method was put forward by Hou Chongsheng in 1994 as a fuzzy adaptive control method for boiler [8], which is characterized by the controller design does not require the system model information, but is based on input and output data to directly calculate and obtain the control value. Literature [5, 9–10] proved the stability of closed-loop system with compact format and partial format dynamic linearization method. The second category of methods is the feature modeling method proposed by Wu Hongxin, et al. The feature modeling method is widely used in the spacecraft and industrial control, which is a kind of modeling method which takes the dynamic characteristics of the object and the performance requirements of the control into account [2]. This method is similar to the full-format dynamic linearization model proposed in literature [5]. The difference lies in that the feature modeling method emphasizes that the feature model is equivalent to the input and output of the original model when the sampling period is sufficiently small [2], while the dynamic linearization method based on the full format considers the situation where time-varying linear system and the original system is equivalent [5, 9–10].

Hou Zhongsheng proposed the fuzzy adaptive control for boiler. Due to its rigorous theory and small amount of calculation, it has broad application prospect in the engineering. After years of development, Hou Zhongsheng designed the fuzzy adaptive control for boiler based on the compact format, the partial format and the full format respectively for the single-input single-output system and multi-input multi-output system.

Based on the PJM (Pseudo Jacobian matrix) identification technique in literature [5], a fuzzy adaptive control method based on the compactness scheme for the boiler is put forward in this paper. And the closed-loop stability of the control method is proved. The simulation experiment of boiler Wood/Berry further shows that the method has stronger tracking ability and is insensitive to the initial value. In this paper, the rate saturation and position saturation are optimized for the actuator at the same time.

2. Problem description

This section briefly describes the related concepts and calculation ideas of the fuzzy adaptive control method for boiler proposed in literature [5]. On this basis, the defects of the existing methods are analyzed, and the problems to be solved in this paper are put forward.

The following multiple input multiple output discrete system is considered:

$$y(k+1) = f\left(y(k), ..., y(k-n_y), u(k), ..., u(k-n_u)\right) , \tag{1}$$

in which, $u(k) \in R^m$, $y(k) \in R^n$, which are the input and output vector at the system time k. Symbols n_y and n_u are unknown integers and $f(\cdot)$ is an unknown non-linear function. Assuming that $f(\cdot)$ is the partial derivative continuity related to $u(k)$, and the system (1) satisfies the generalized Lipschitz hypothesis, theorem 1 [5] can be obtained.

Theorem 1. For the nonlinear system (1) that satisfies the generalized Lipschitz hypothesis as the partial derivative continuity related to $u(k)$, when $\|\Delta u(k)\| \neq 0$, there must be a time-varying parameter $\Phi_{\mathrm{c}}(k) \in R^{n\times m}$ known as the PJM (Pseudo Jacobian matrix), so that the system (1) can be transformed into the compact form dynamic linearization (CFDL) as follows

$$\Delta y(k+1) = \Phi_{\mathrm{c}}(k)\,\Delta u(k) , \tag{2}$$

where

$$\Phi_{\mathrm{c}}(k) = \begin{bmatrix} \phi_{11}(k) & \phi_{12}(k) & \cdots & \phi_{1m}(k) \\ \phi_{21}(k) & \phi_{22}(k) & \cdots & \phi_{2m}(k) \\ \vdots & \vdots & \ddots & \vdots \\ \phi_{n1}(k) & \phi_{n2}(k) & \cdots & \phi_{mm}(k) \end{bmatrix} \in R^{n\times m} . \tag{3}$$

and for any time k, $\|\Phi_{\mathrm{c}}(k)\|$ is bounded.

The fuzzy adaptive control of boiler based on the compact format dynamic linearization is to use the method of parameter identification to dynamically calculate the value of PJM time-varying parameter and control it on this basis. The detailed calculation steps can be found in literature [9–10]. In the existing method, only literature [10] considered the problem of the incomplete non-linear runaway of boiler. For the actual physical system, the actuator execution capability is limited, which is reflected in the control of the magnitude and rate of change. The execution capability of the actuator can be completely expressed as the following

$$\begin{cases} \Delta u_{\min}(k) \leq \Delta u(k) \leq \Delta u_{\max}(k) , \\ \\ u_{\mathrm{L}} \leq u(k) \leq u_v , \end{cases} \tag{4}$$

in which, $\Delta u_{\min}$ and $\Delta u_{\max}$ stand for the minimum and maximum values of the control variable rate, respectively. u_{L} and u_v stands for the minimum and maximum values of the control amplitude, respectively.

3. Nonlinear runaway optimization of the fuzzy adaptive control for boiler

In this section, an optimized fuzzy adaptive control for boiler based on the compact format boiler is put forward, and a control algorithm by comprehensively analyzing the execution ability of the actuator is provided.

In order to strictly analyze the closed loop stability of the improved algorithm, the following assumptions are made:

Hypothesis 1: There is a sufficiently large λ that makes $\Phi E^{-1}\left(F+M^{\mathrm{T}}x\right)$ positive definite.

If the assumption 1 is not satisfied, it shows that the improved algorithm cannot guarantee the closed-loop stability of the system in the event of the non-linear boiler runaway, and it requires more complicated control algorithm so as to carry out effective control.

Theorem 2 can be proved based on Hypothesis 1.

Theorem 2: For the nonlinear system (1), when the amplitude $\Delta u\left(k\right)$ is bounded, the iterative algorithm proposed by an identification scheme below has the following properties when the hypothesis 1 is met: When $y*\left(k+1\right)=y*=\mathrm{const}$, there is a positive number$\lambda_{\min}>0$, which enables the following when $\lambda\geq\lambda_{\min}$:

1) The system tracking error sequence is bounded, that is, $\left\|y\left(k+1\right)+y*\right\|$ is bounded.

2) The closed-loop system is BIBO (Bounded-input bounded-output) stable, that is, the output sequence $\left\{y\left(k\right)\right\}$ and the input sequence $\left\{u\left(k\right)\right\}$ are bounded.

Proof.

Prove that $\left\|\tilde{y}\left(k\right)\right\|=\left\|y\left(k\right)-\hat{y}\left(k\right)\right\|$ is bounded. According to the theorem in literature [5], $\left\|\Phi_{\mathrm{c}}\left(k\right)-\hat{\Phi}_{\mathrm{c}}\left(k\right)\right\|$ is bounded, and $\Delta u\left(k\right)$ is bounded, assuming that

$$\left\|\Phi_{\mathrm{c}}\left(k\right)-\hat{\Phi}_{\mathrm{c}}\left(k\right)\right\|\left\|\Delta u\left(k\right)\right\|\leq b\,. \tag{5}$$

Then the following can be obtained

$$\begin{gathered}\left\|\tilde{y}\left(k+1\right)\right\|=\left\|y\left(k+1\right)-\hat{y}\left(k+1\right)\right\|=\left(1-K\right)\left\|y\left(k\right)+\tilde{\Phi}_{\mathrm{c}}\left(k\right)\Delta u\left(k\right)\right\|\leq\\ \left(1+K\right)\left(\left\|\tilde{y}\left(k\right)\right\|+\left\|\tilde{\Phi}_{c}\left(k\right)\Delta u\left(k\right)\right\|\right)\leq\left(1+K\right)\left\|\tilde{y}\left(k\right)\right\|+\left(1+K\right)b\leq...\leq\\ \left(1+K\right)^{k}\left\|\tilde{y}\left(1\right)\right\|+\frac{\left(1+k\right)b\left(1-\left(1-K\right)^{k}\right)}{K}\end{gathered} \tag{6}$$

Hence $\left\|\tilde{y}\left(k\right)\right\|$ is bounded, assuming it to be c, that is, $\left\|\tilde{y}\left(k\right)\right\|\leq c\,.$

Prove that there is λ that enables

$$I-\Phi_{\mathrm{c}}\left(k\right)S\left(k\right)\left(\hat{\Phi}_{\mathrm{c}}\left(k\right)\hat{\Phi}_{\mathrm{c}}^{T}\left(k\right)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{T}\left(k\right), \tag{7}$$

the absolute values of the eigenvalue are all less than 1. In this case, $S(k)$ is a diagonal matrix, $S_i(k)$ stands for the kth diagonal element in the matrix $S(k)$. In addition, denote $delta(k)$ as an m-dimensional vector, and ε_0 is a positive number greater than 0. And $S(k)$ and $\delta(k)$ satisfy the following.

for $i = 1 : m$
if $\left(E^{-1}F\right)_i \leq \varepsilon_0$ then

$$S_i(k) \leftarrow \frac{\left(E^{-1}\left(F + M^{\mathrm{T}}x\right)\right)_i}{\varepsilon_0}$$

$$\delta_i(k) \leftarrow \frac{(x)_i}{S_i} - \left(E^{-1}F\right)_i$$

else

$$S_i(k) \leftarrow \frac{\left(E^{-1}\left(F + M^{\mathrm{T}}x\right)\right)_i}{\left(E^{-1}F\right)_i}$$

$$\delta_i(k) \leftarrow 0$$

It is easy to see that

$$x = S(k)\, E^{-1}F + S(k)\,\delta(k) \tag{8}$$

Use $\|\cdot\|_2$ to represent the spectral norm of the matrix, $\rho(\cdot)$ to represent the spectrum of the matrix. As $\Phi_{\mathrm{c}}(k)$, $S(k)$, $\hat{\Phi}_c^{\mathrm{T}}(k)$ and $\delta(k)$ are all bounded, assuming that

$$\begin{aligned} &\|\Phi_{\mathrm{c}}(k)\|_2 \|S(k)\|_2 \left\|\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right\|_2 \leq e_1 \|S(k)\|_2 \left\|\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right\|_2 \leq \\ &\leq e_2 \|\Phi_{\mathrm{c}}(k)\|_2 \|S(k)\,\delta(k)\|_2 \leq e_3 \,. \end{aligned} \tag{9}$$

Take $e_0 = \max\{e_1, e_2\}$, $\lambda_{\min} = e_0 + \rho\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right)$, as $\left(\hat{\Phi}_{\mathrm{c}}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) + \lambda I\right)^{-1}$ is a symmetric matrix, and when $\lambda > \lambda_{\min}$, the following is established

$$\left\|\left(\hat{\Phi}_{\mathrm{c}}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) + \lambda I\right)^{-1}\right\|_2 = \rho\left(\left(\hat{\Phi}_{\mathrm{c}}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) + \lambda I\right)^{-1}\right) < \frac{1}{e_0} \,. \tag{10}$$

Then it is further established that

$$\begin{aligned} &\rho\left(\Phi_c(k)\, S(k)\left(\hat{\Phi}_c(k)\,\hat{\Phi}_c^T(k) + \lambda I\right)^{-1} \hat{\Phi}_c^T(k)\right) \leq \\ &\|\Phi_c(k)\|_2 \|S(k)\|_2 \left\|\left(\hat{\Phi}_c(k)\,\hat{\Phi}_c^T(k) + \lambda I\right)^{-1}\right\|_2 \times \left\|\hat{\Phi}_c^T(k)\right\|_2 < 1 \,. \end{aligned} \tag{11}$$

It can be seen from the Hypothesis 1 that, when $\lambda > \lambda_{\min}$, all the absolute values of the eigenvalue of Equation (11) are less than 1.

Prove that the tracking error is bounded. As can be seen from Step 2

$$\rho\left(I-\Phi_{\mathrm{c}}(k)\,S(k)\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right)<1\,. \tag{12}$$

Then there is sufficiently small $\in$ and norm $\|\cdot\|$ that enables the following

$$\begin{gathered}\left\|I-\Phi_{\mathrm{c}}(k)\,S(k)\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right\|\leq\in+\\ \rho\left(I-\Phi_{\mathrm{c}}(k)\,S(k)\times\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right)<1\end{gathered} \tag{13}$$

For any k, take the following

$$\left\|I-\Phi_{\mathrm{c}}(k)\,S(k)\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right\|<d_1<1$$

$$\left\|\Phi_{\mathrm{c}}(k)\,S(k)\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right\|<d_2 \tag{14}$$

Then

$$\begin{aligned}&\|e(k+1)\|=\|y*(k+1)-y(k+1)\|=\|y*(k+1)-y(k)-\Phi_{\mathrm{c}}(k)\,S(k)\times\\ &\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\,(y*(k)-\hat{y}(k))-\Phi_{\mathrm{c}}(k)\,S(k)\,\delta(k)\Big\|\leq\\ &\left\|I-\Phi_{\mathrm{c}}(k)\,S(k)\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right\|\times\|y*(k)-y(k)\|+\\ &\left\|\Phi_{\mathrm{c}}(k)\,S(k)\times\left(\hat{\Phi}_{\mathrm{c}}(k)\,\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)+\lambda I\right)^{-1}\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)\right\|\|\tilde{y}(k)\|+\|\Phi_{\mathrm{c}}(k)\,S(k)\,\delta(k)\|\\ &\leq d_1\|e(k)\|+d_2c+e_3\leq\ldots\leq d_1^k\|e(1)\|+\tfrac{(d_2c+e_3)\left(1-d_1^k\right)}{1-d_1}\,.\end{aligned}$$

Then $\|e(k)\|$ is bounded, assuming its boundary isf_0, that is, $\|e(k)\|\leq f_0$.

As $y*(k)$ is bounded, it can be known that $y(k)$ is bounded. Also because in the process of solving x, the control value position saturation limit is added, $\|u\|$ can meet the constraints, hence it is bounded. Then it can be further known that $u(k)$ is bounded.

Inference 1. If the filter is not used, that is, $\hat{y}(k)=y(k)$. And when $\delta(k)=0$ is established, the conclusion in Theorem 2 can be strengthened as the following:

1) system tracking error sequence convergence;

2) The closed-loop system is BIBO stable, that is, the output sequence and the input sequence are bounded.

Proof.

$$\|e(k+1)\| \leq \|y*(k+1) - y(k) - \Phi_{\mathrm{c}}(k) S(k) \times \left(\hat{\Phi}_{\mathrm{c}}(k) \hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) + \lambda I\right)^{-1}$$
$$\hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k)(y*(k) - \hat{y}(k))\Big\| \leq \left\| I - \Phi_{\mathrm{c}}(k) S(k) \left(\hat{\Phi}_{\mathrm{c}}(k) \hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) + \lambda I\right)^{-1} \hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) \right\|$$
$$\times \|y*(k) - y(k)\| \leq d_1 \|e(k)\| \ldots \leq d_1^k \|e(1)\| . \tag{15}$$

Therefore, $\lim_{k\to\infty} \|y(k+1) - y*\| = 0$. Hence the conclusion 1) is proved. The proving of the conclusion 2) is similar to the proving of the conclusion 2 in Theorem 2.

The physical meaning of $\delta(k) \equiv 0$ in Inference 1 is that under the premise of the absence of the constraints of equation (7), the result obtained by the calculation only according to Equation (7) is not zero. In the actual system, due to the existence of noise and numerical calculation error, the resulting value from solving equation (7) will rarely be zero, therefore, the hypothesis in the actual system is of certain significance.

4. Simulation experiment

Boilers are widely used in the chemical industry. However, the delay occurred inside the boiler has caused great difficulties in the design of the control law. The fuzzy adaptive control for boiler can be used to conduct effective tracking control. In this simulation, Wood/ Berry boiler is used, as shown in Fig. 1, in which, u_1 stands for the reflux rate (IB/min), u_2 stands for the steam flow (IB/min), y_1 stands for the upper part component (mol% methanol), and y_2 stands for the bottom part component (mol% methanol). The following discrete system is used as the Wood/Berry boiler.

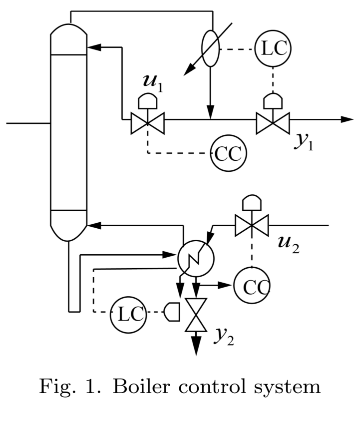

Fig. 1. Boiler control system

$$\begin{cases} y_1(z) = \frac{0.7665}{z-0.9419} u_1(z) + \frac{0.9z^{-2}}{z-0.9535} u_2(z), \\ y_2(z) = \frac{0.6055z^{-6}}{z-0.9124} u_1(z) + \frac{1.3472z^{-2}}{z-0.90311} u_2(z). \end{cases}$$

The expected output signal is as the following

$$y_1^*(k) = \begin{cases} 40, k \le 1000 \\ 90, k > 1000 \end{cases}$$

$$y_2^*(k) = \begin{cases} 40, k \le 1000 \\ 85, k > 1000 \end{cases} \tag{16}$$

In order to compare the control effect of the original method and the improved method upon the occurrence of non-linear runaway of the boiler, the calculation method for $\hat{\Phi}_{\mathrm{c}}(k)$ before the improvement is described as the following:

$$\hat{y}_i(k+1) = \hat{y}_i(k) + \Delta u^{\mathrm{T}}(k) \hat{\phi}_i^T(k) + k_i \tilde{y}_i(k), \tag{17}$$

$$\hat{\phi}_i^{\mathrm{T}}(k+1) = \hat{\phi}_i^{\mathrm{T}}(k) + 2\Delta u(k) \left(\|\Delta u(k)\|^2 + \mu_i \right)^{-1} \times \left(\tilde{y}_i(k+1) - F_i \tilde{y}_i(k) \right), \tag{18}$$

in which $\hat{y}_i(k)$ is the estimate value of the ith output component and $\tilde{y}_i(k) = y_i(k) - \tilde{y}_i(k)$ is the corresponding estimate error. Quantity $F_i = 1 - k_i$, and k_i is the corresponding element on the diagonal of the matrix. $\hat{\phi}_i^{\mathrm{T}}(k)$ is the ith row vector of the matrix $\hat{\phi}_{\mathrm{c}}(k)$. The calculation method for $u(k)$ before the improvement is as the following:

$$\begin{aligned} & u(k) = u(k-1) + \hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) \left[\hat{\Phi}_{\mathrm{c}}(k) \hat{\Phi}_{\mathrm{c}}^{\mathrm{T}}(k) + \alpha \right]^{-1} \times \\ & [y*(k+1) - \hat{y}(k) - K\tilde{y}(k)], \|\Delta u(k)\| \le \delta, \end{aligned} \tag{19}$$

$$u(k) = u(k-1) + \delta \cdot \mathrm{sgn}(\Delta u(k)), \|\Delta u(k)\| > \delta. \tag{20}$$

In the simulation process of this paper, $\alpha = \mathrm{diag}\{0.003, 0.0015\}$ and $\delta = 0.02$. The following parameters are shared with the improved algorithm before and after the improvement: the sampling cycle $T_s = 1s$, $K = \mathrm{diag}\{0.9, 0.9\}$, $\mu_1 = \mu_2 = 9$, and PJM is the initial value of the PJM parameter.

$$\hat{\Phi}_{\mathrm{c}}(0) = \begin{bmatrix} 910 & 750 \\ 450 & 520 \end{bmatrix}.$$

At the same time limiting the execution capacity of the controlled system actuator as the following

$$\begin{cases} 0 \le \mu_1 \le 1, & -0.02 \le \Delta\mu_1 \le 0.02 \\ 0 \le \mu_2 \le 4, & -0.02 \le \Delta\mu_2 \le 0.02 \end{cases} \tag{21}$$

On this basis, the algorithm is simulated before and after the improvement and Fig. 2 can be obtained.

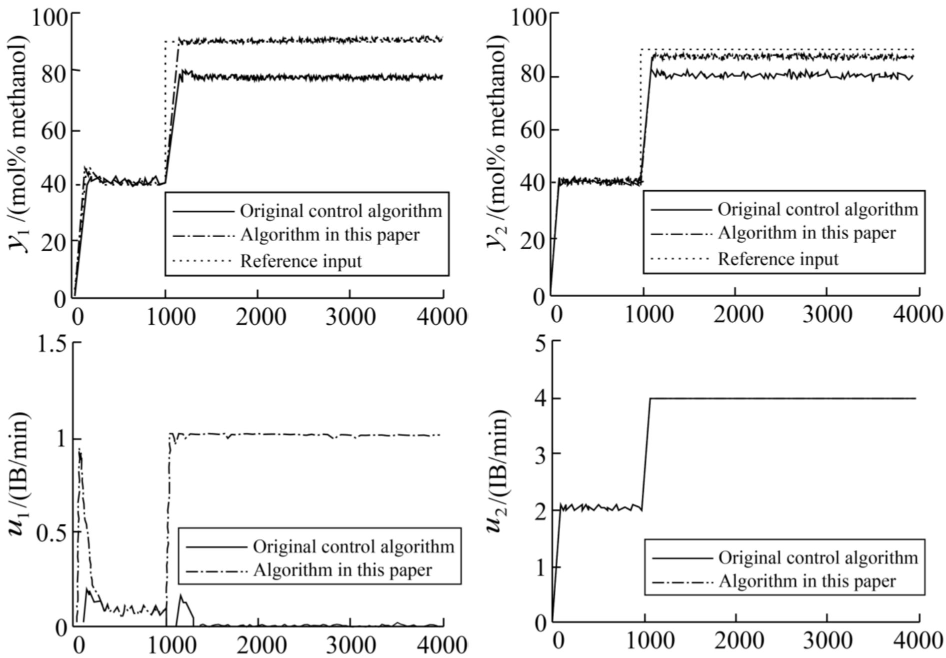

Fig. 2. Control performance comparison chart

In order to compare the sensitivity of the control algorithm to the initial parameters before and after the optimization of the initial parameters, assume the original parameter

$$\hat{\Phi}_c(0) = \begin{bmatrix} 1000 & 1000 \\ 1000 & 1000 \end{bmatrix}.$$

Then, Fig. 3 can be obtained after performing simulation. In the absence of limited execution capacity, the boiler fuzzy adaptive control can better track the signal. But it can be found after comparing with Fig. 3 that, the fuzzy adaptive control of the boiler before the improvement shows significant static difference upon the occurrence of the non-linear runaway of the boiler. This is because the controller in the calculation of control output does not take into account the implementation of the actuator capacity, indirectly causing the situation that the system cannot correct the errors of the PJM parameters, and finally leading to the violent jitter in the control algorithm, and basically losing the capability to track the reference input. Under the improved boiler fuzzy adaptive control algorithm, it fully considers the execution capability of the actuator, which can effectively track the reference input, showing the effectiveness of the algorithm.

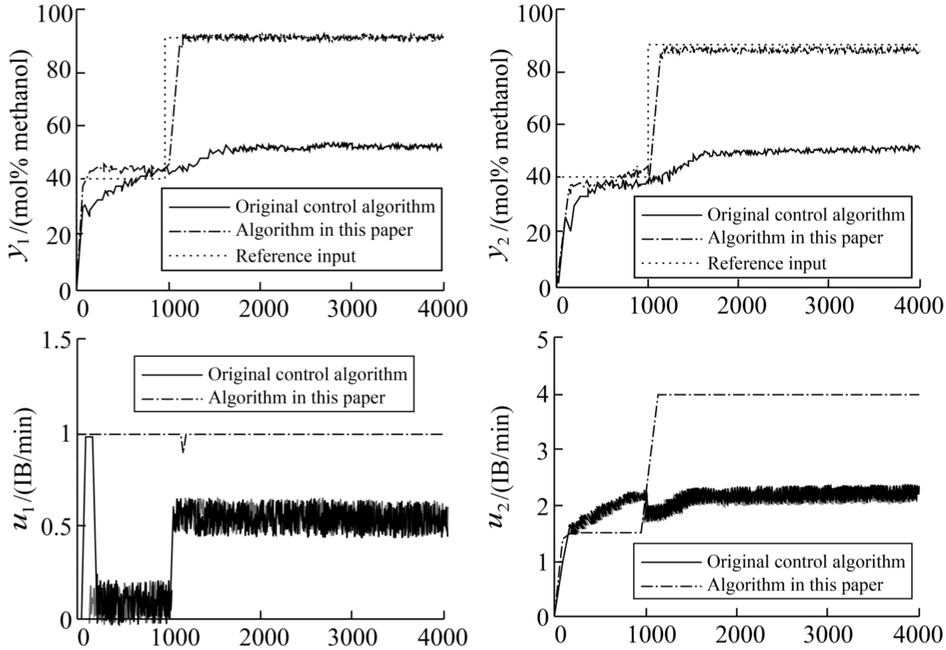

Fig. 3. Control performance comparison chart after the change of the initial parameters

5. Conclusion

In this paper, a fuzzy adaptive control algorithm for boiler is proposed to solve the failure to deal with the non-linear runaway problem of the boiler. And the closed loop stability of the algorithm is proved rigorously. The algorithm has the advantages of simple to implement and small calculation amount. The control effects of the algorithm combined with the Wood/Berry model before and after the improvement are compared. The simulation results show that, the improved algorithm has the advantages of strong tracking capability and weak dependence on the initial parameters, which can effectively deal with the non-linear runaway problem of the boiler.

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