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Application of pH Control based on Adaptive PID in Acid-alkali Neutralization Reaction

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Abstract: An adaptive PID controller based on artificial neuron is designed to improve the interference immunity of pH system in acid-alkali reaction. By using the learning algorithm of artificial neuron, parameter self-tuning and adaptability are realized in the control, which solves the problems of long adjustment time, large overshoot and poor anti-interference of PID control in acid-alkali reaction. Simulation results show that the adaptive PID controller has shorter repose time and stronger robustness compared with conventional PID controller.

Key Words: Adaptive PID, artificial neuron, pH control, neutralization reaction

1 Introduction

The control of pH is a typical process control system, which widely exists in industrial productions. But the control of pH has been one of difficult problems in the field of industrial control, because of nonlinear properties in acid-alkali neutralization reaction and large time-delay in control process such as pH measurement. Wiener model identification and predictive control are proposed in pH neutralization process in Ref.[1]. A multi-objective optimization based dynamic fuzzy recurrent neural network modeling method is designed to control the pH neutralization process by generalized predictive controller in Ref.[2]. Differential evolution based nonlinear model predictive control is applied to a pH neutralization system in Ref.[3]. The algorithm fully makes use of the titration curve model to obtain the appropriate initial values of nonlinear optimization problem. A control method named set range intelligent controller is presented in Ref.[4]. In this method, upper limit and lower limit for the set range are regarded as the set points respectively, and both constructed controllers are scheduling dynamically by neutralization pH in order to control pH within the given set range.

However, PID control is used in most of the industrial production and complex control algorithms are difficult to realize due to the actual production conditions. Improved PID control with simple structure is better to solve practical pH control problems. So an adaptive PID controller based on artificial neuron is designed in this paper, and it has wider application value.

2 Problem Description

In the chemical process, acid-alkali neutralization reaction is carried out in continuous stirred tank reactor(CSTR). The press of pH control is shown in Fig. 1.

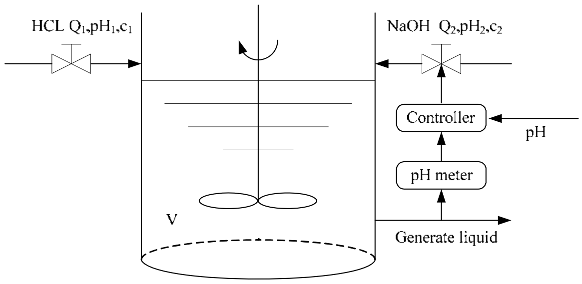

Fig. 1: Process of pH control

In Fig.1, Q_1 is flow rate of HCL; pH_1 is pH value of HCL; c_1 is hydrogen ion concentration; Q_2 is flow rate of NaOH; pH_2 is pH value of NaOH; c_2 is hydroxide ion concentration; pH is given value. Q_2 is controlled by the controller in order to consistent pH value of the generate liquid with pH.

In neutralization reaction, acid-alkali neutralization process is typical nonlinear process. If 20*ml* of HCL with concentration of 0.1*mol*/*L* is titrated by NaOH with concentration of 0.1*mol*/*L*, the titration curve is shown in Fig.2.

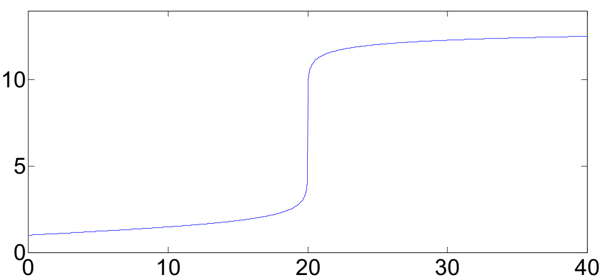

Fig. 2: Titration curve of acid-alkali neutralization reaction

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According to Ref.[5], the dynamic model of acid-alkali neutralization reaction can be expressed as follow

$$\begin{cases} \dot{x}_1 = -\dfrac{Q_1+Q_2}{V}x_1 + \dfrac{c_1}{V}Q_1 \\ \dot{x}_2 = -\dfrac{Q_1+Q_2}{V}x_2 + \dfrac{c_2}{V}Q_2 \\ y = -\lg\left(\sqrt{\dfrac{(x_2-x_1)^2}{4}+K_w} - \dfrac{x_2-x_1}{2}\right) \end{cases} \quad (1)$$

Where, x_1 is hydrogen ion concentration before reaction in neutralization reaction pool; x_2 is hydroxide ion concentration before reaction in neutralization reaction pool; V is volume of the reaction pool; K_w is equilibrium constant; y is pH value of the generate liquid. Without considering the impacts of temperature and liquid level, formula (1) is able to descript reaction process in condition of full reaction.

3 Controller Design

PID control is used in most of the actual industrial process because the controller has better stability and reliability. PID control algorithm can be expressed as follow

$$u(t) = K_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + T_d\frac{de(t)}{dt}] \quad (2)$$

Where, $e(t)=r(t)-y(t)$; $r(t)$ is desired input and $y(t)$ is actual output; $u(t)$ is output of controller; K_p is proportional gain; T_i is integration time constant; T_d is derivative time constant.

In the computer control system, formula (2) must be expressed in discrete form. The digital PID control algorithm can be expressed as follow

$$\begin{aligned} &u(k) = u(k-1) + \Delta u(k) \\ &\Delta u(k) = K_p[x_1(k) + \frac{T}{T_i}x_2(k) + \frac{T_d}{T}x_3(k)] \\ &x_1(k) = e(k) - e(k-1) \\ &x_2(k) = e(k) \\ &x_3(k) = e(k) - 2e(k-1) + e(k-2) \end{aligned} \quad (3)$$

Where, T is sampling time; $u(k)$ is output of controller in the k-th sampling time; $e(k)$ is error in the k-th sampling time; K_p, T_i and T_d are control parameters.

Parameter tuning of PID is difficult to realize in actual process, especially when the control object could not be accurately described by mathematical model. And PID control is designed for the linear system. While pH control is typical non-linear system, PID control can not achieve the desired performances for random system interferences. In order to retain advantages and improve deficiencies of PID control, an adaptive PID controller based on artificial neuron is designed in this paper. Artificial neural network has self-learning and adaptive features, and many studies prove that neural network significantly improves the control performance of nonlinear system. With combination of artificial neural and PID control algorithm, parameter self-tuning and adaptive ability can be achieved in the control process. The structure of adaptive PID controller is shown in Fig. 3.

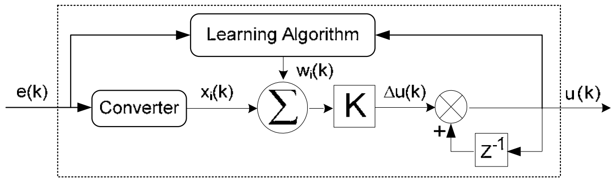

Fig. 3: Structure of adaptive PID controller

Where, $e(k)$ is input; $u(k)$ is output; $x_i(k)(i=1,2,3)$ is variable of learning, which is shown in formula (3); $w_i(k)$ is weight corresponding to $x_i(k)$; $K(K>0)$ is proportional gain.

The adaptive PID control is realized by adjusting weights through leaning algorithm. The algorithm can be expressed as follow

$$\begin{aligned} &\Delta w_i(k) = \eta_i z(k)u(k)x_i(k) + \beta\Delta w_i(k-1) \\ &\Delta w_i(k-1) = w_i(k-1) - w_i(k-2) \\ &w_i(k) = w_i(k-1) + \Delta w_i(k) \\ &(i=1,2,3) \end{aligned} \quad (4)$$

Where, $z(k)= e(k)$ and η_i is learning rate corresponding to $w_i(k)$; β is inertial coefficient. In general, β =0.05. For ensuring convergence of formula (4), it can be standardized as follow

$$\begin{aligned} &\overline{w_i}(k) = w_i(k) / \sum_{i=1}^{3}|w_i(k)| \\ &(i=1,2,3) \end{aligned} \quad (5)$$

Then, output of the controller can be expressed as follow

$$\begin{aligned} &\Delta u(k) = K\sum_{i=1}^{3}\overline{w_i}(k)x_i(k) \\ &u(k) = u(k-1) + \Delta u(k) \end{aligned} \quad (6)$$

Comparing with formula (3), formula (6) can solve parameter self-tuning problem. And the algorithm is more applicable to pH control because artificial neural can realize online adjustment of control parameters. The adaptive PID controller is designed according to dynamic model expressed as formula (1) in neutralization reaction, which can solve the problems of long adjustment time, large overshoot and poor anti-interference in PID controller.

4 Simulation Experiment

Control performance of the adaptive PID controller is examined by Matlab simulation. According to Fig.1, simulation model parameters are set as follow $Q_1=0.03(m^3/s)$, $pH_1=2$, $c_1=10^{-2}(mol/L)$, $pH_2=12$, $c_2=10^{-2}(mol/L)$, $V=75(m^3)$, $pH=7$, $K_w=10^{-14}(mol/L)^2$ in 25°C

In the same simulation conditions，the system response curves of adaptive PID control and PID control are shown in Fig. 4.

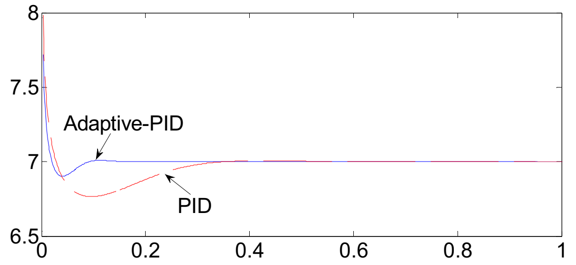

Fig. 4: Response curves of control

But the reaction is carried out in large container, acid and alkali are failed to fully mix in some time. It will cause system interference that the concentration of generate liquid in the pool will be changed. In the simulation experiment, a random interference will be added at third second. The system response curves of adaptive PID control and PID control are shown in Fig. 5.

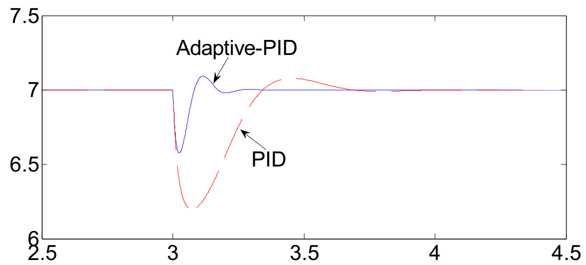

Fig. 5: Response curves of control with system interference

According to the simulation results, performance indicators of pH control are shown in Tab.1.

Table 1: Dynamic Performance Index

	No System Interference		System Interference	
	Adaptive PID	PID	Adaptive PID	PID
t_p	0.040	0.100	0.025	0.075
t_s	0.150	0.550	0.330	0.980
σ%	1.39%	3.34%	6.07%	11.43%

In Tab.1, t_p is peak time and it shows the sensitivity of system; t_s is transition time and it shows the adaptability of system; σ% is overshoot and it shows the stability of system. From the table, we can conclude that pH control based on adaptive PID has some disadvantages, such as less overshoot and stronger adaptability. The simulation results show that the adaptive PID controller is more suitable for pH system than PID controller.

5 Conclusion

In comparison with PID control, the pH control based on adaptive PID has the following advantages

- The pH control parameters can be automatically adjusted according to actual situation.
- The adaptive PID controller has stronger adaptability and robustness.
- Simulation results indicate that the dynamic performances of pH control system based on adaptive PID are significantly improved.

So, the pH control based on adaptive control can be widely applied to industrial process.

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