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Simulation and Experiment Study of Optimizational PID Control with Changing Integration Rate

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Abstract

This paper is to demonstrate an optimizational PID control with changing integration rate approach, and it was validated and researched by applying to the two-linked tanks system. Analyzed the control principle of variable integral PID in this research, and optimized the variable function of variable integral PID control to improve the design.Deduced the improved variable integral PID control algorithm, and it was applied to the two-linked tanks system. And then made a simulation system and application experiment in the advanced process control experimental apparatus to value it. The results show that the optimizational variable integral PID control enables the system to improve the rapidity, stationarity and accuracy, also shows that the correctness and superiority of the control method. It really an useful method to provide a advanced way for the control system.

Keywords*: variable integral PID control, optimization design, simulation, experimental study, two-linked tanks*

1. Introduction

PID control is a control strategy that has been successfully used over many years [1]. Many of them are classic PID control algorithm,the integral increment is unchanging because the integral coefficient k_{i} is constant throughout the control process.In order to improve the rapidity and accuracy of the system, the integral term of the system is that the integral action should be weakened or even no when the systematic error becomes larger, it should be strengthened when the deviation becomes smaller. The system will product the overshoot, and even the integral saturation when the integral coefficient is too large, and the system can not eliminate the static error when the integral coefficient is too small in long time. Variable integral PID control can change the speed of the integral according to the error size of system, which plays a role in improving the system quality [2-5]. But variable integral PID control is a constant velocity in changing the speed of the integral, that is to say it is inversely proportional linear relationship to the error, Is there a better way? An improving PID controller [6] with changing integration rate is put forward in this paper. The purpose is to further adjust the integral function in the system, also to further improve the rapidity and accuracy of the system output.

2. The Principle of PID Control with Changing Integration Rate

The basic idea of variable integral PID control is to try to change the cumulative speed of the integral term, and enable the cumulative speed to correspond to the size of error [3-5]. Therefore setting $f(e(k))$,it is the function of error $e(k)$.When $|e(k)|$ becomes larger, $f(e(k))$ becomes smaller,to the contrary it becomes larger.The integral term expression of the variable speed integral PID control is Eq.1.

$$u_{\mathrm{i}}(k) = K_{\mathrm{i}}\left\{\sum_{i=0}^{k-1} e(i) + f(e(k))e(k)\right\}T \tag{1}$$

The relationship between function $f(e(k))$ and the error value $e(k)$ can be linear or nonlinear, it can be seen Eq.2.

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$$f(e(k)) = \begin{cases} 1 & |e(k)| < B \\ \dfrac{A-|e(k)|+B}{A} & B \le |e(k)| \le A+B \\ 0 & |e(k)| > A+B \end{cases} \quad (2)$$

The value of $f(e(k))$ changes between 0 and 1. When the error absolute value $|e(k)|$ is greater than the given separation range $A+B$, $f(e(k))=0$,the error value $e(k)$ is no longer accumulated continuously. When the error absolute value $|e(k)|$ is less than B, $f(e(k))=1$,it is the same as the common PID control, the integral action achieve the highest speed. When the error absolute value $|e(k)|$ is between B and $A+B$, the part of the current error value $e(k)$ is accumulated and calculated. Its value changes between 0 and 1 with the value size of $|e(k)|$.

Therefore, the integral speed between $K_i\sum_{i=0}^{k-1} e(i)T$ and $K_i\sum_{i=0}^{k} e(i)T$ .Variable speed integral PID algorithm is Eq.3.

$$u(k) = K_p e(k) + K_i \left\{ \sum_{i=0}^{k-1} e(i) + f(e(k))e(k) \right\} T + K_d \left[e(k) - e(k-1) \right] \quad (3)$$

3. Improved Variable Integral PID Control Algorithm Design

According to the principal of the variable integral PID control,the piecewise function of Eq.2 can be described by graph, and the result is shown in Figure 1.

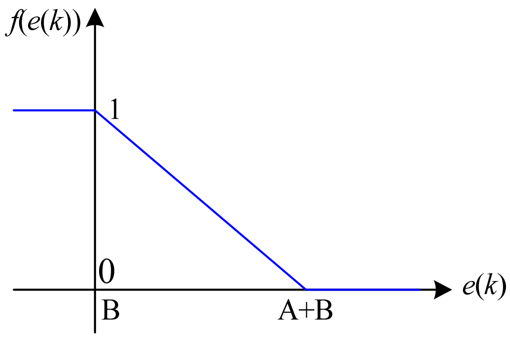

Figure 1. The $f(e(k))$ curve before improvement

From Figure.1, it can be seen that its variable integral term changes with the error in constant velocity. The control effect is better than the ordinary PID control and the integral separate PID control, it also enhances rapid when the system has large error value, and improves the accuracy of the system when it has small error value. But can this method be improved to optimize the control system? So, an improving PID control with changing integration rate is put forward in this paper. The $f(e(k))$ function design is the improved work mainly.When $|e(k)| \ge B$ and $|e(k)| \le A+B$,the $f'(e(k))$ is defined negative arctangent function, that is $f'(e(k)) = -\arctan(e(k))$,considering the relationship between amplitude size and coordinate translation, the result can be shown as Eq.4.

$$f'(e(k)) = -\frac{1}{2}\arctan(10e(k) - 7) + \frac{1}{2} \quad (4)$$

when the error absolute value $|e(k)| < B$ and error absolute value $|e(k)| > A+B$, $f'(e(k))$ is unchanged, then the function $f'(e(k))$ is can be shown as Eq.5.

$$f'(e(k)) = \begin{cases} 1 & |e(k)| \le B \\ -\frac{1}{2}\arctan(10e(k)-7)+\frac{1}{2} & B < |e(k)| \le A+B \\ 0 & |e(k)| > A+B \end{cases} \quad (5)$$

The graphical representation of the improved piecewise function is received and shown in Figure 2.According to Figure 2,when the error absolute value $|e(k)|$ is between *B* and *A+B*,it shows $f'(e(k)) < f(e(k))$ in large error part, it can make that the system further reduces integral effect, and further improves the rapidity of the system output. To the contrary ,it shows $f'(e(k)) > f(e(k))$ in small error part, it can make that the system further increases integral effect, and further improves the accuracy of the system output.

In order to prove the correction of the function $f'(e(k)) = -\arctan(e(k))$,According to Eq.5,set *B* = 0.4, *A* = 0.6 and run commands in MATLAB:

```
A = 0.4;
B = 0.6;
e = A: 0.001: A+B;
f=-1/2*Tanh(10*e-7)+1/2;
plot (e, f)
```

The response curve is shown in Figure 3. The output value range and shape of the curve in Figure 3 is almost exactly the same in Figure 2.

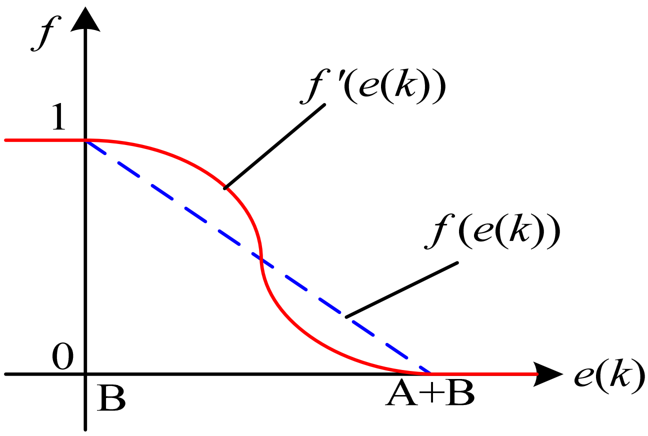

Figure 2. $f'(e(k))$ curve after improvement

Through above optimization improvement, the improved variable integral PID control algorithm is shown in Eq. 6.

$$u(k) = K_p e(k) + K_i \left\{ \sum_{i=0}^{k-1} e(i) + f'(e(k))e(k) \right\} T + K_d \left[e(k) - e(k-1) \right] \quad (6)$$

It is very similar for Eq.6 and Eq.3,but it is two completely different functions for $f'(e(k))$ and $f(e(k))$.

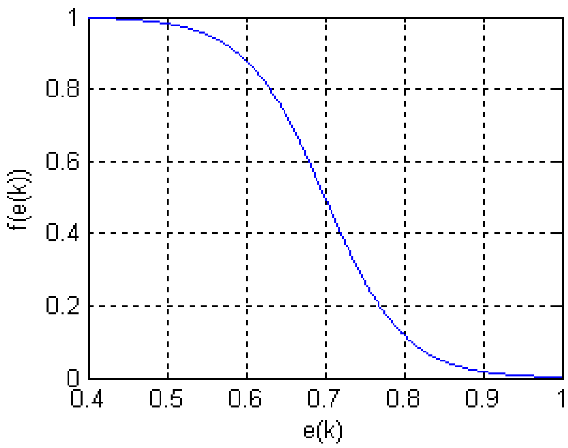

Figure 3.The response curve of the negative arctangent function

4. Simulation and Experiment Study

Simulation and experiment study run on the advanced process control experimental apparatus (THKGK-1). It is a complex control system, and can run the experiments of temperature control, pressure control, flow control, level control, etc..As shown in Figure 4.Two-link tanks level control is one of them, as a special case of process control, the liquid level control is one of the hot research for many process control experts. System status, system parameters and control algorithms directly affect the control accuracy, because of its own lags and non-linear characteristics [7,8].

Figure 4.The picture of advanced process control

4.1. The Model of Two-link Tanks

The principle of two-link water tanks is cascaded two different volume physical tanks. As shown in Figure 5.It's mathematical model is the product of the mathematical model of the two single-tank, that is to say it can be described by the two first-order inertial link, adding the time delay of the system,the transfer function [7,8] can be shown as Eq. 7.

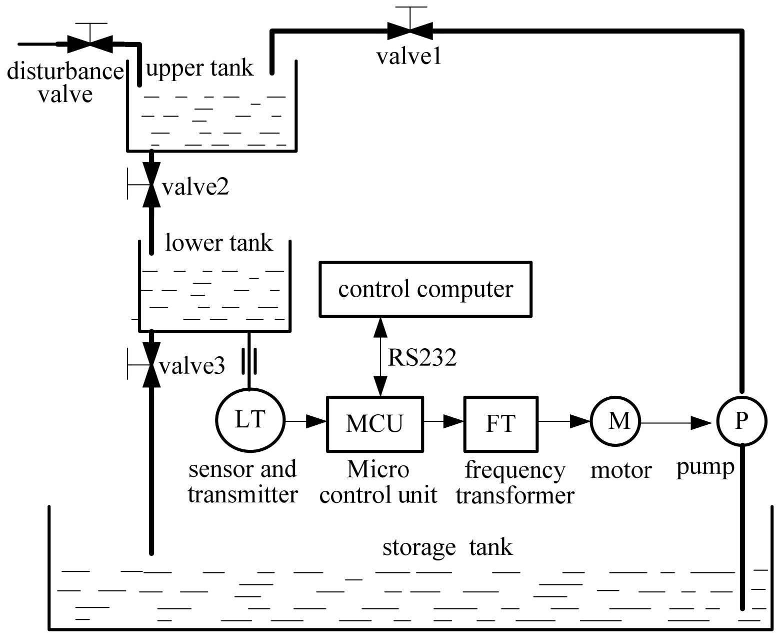

Figure 5. The structure diagram of two-link tanks system

$$G(s) = G_1(s)G_2(s) = \frac{K}{(T_1 s+1)(T_2 s+1)} e^{-\tau s} \tag{7}$$

Where,K is Proportion coefficient of two-link tanks system,T_1 and T_2 are time constant of two single-tanks system.

According to the principle of two-link water tanks and structure diagram in Figure 5,the parameters of transfer functioncan be get by experimental method [9].

4.2. Program Simulation

The transfer function of the two-link tanks system has achieved according to test methods of the two-link tanks mathematical model in reference[8], the lag time of the two-link tanks system is closely related to the valve's opening size of the water tank inlet valve and the outlet value, so the system has different transfer function in different status[10]. Finally,the transfer function is achieved by calculating the experimental data in the repeated experiment. The result can be shown as Eq.8.

$$\frac{1}{(65s+1)(9.04s+1)} \cdot e^{-90s} \tag{8}$$

It is proposed that the sampling time is 2 second, the step response simulation test is proceeded under two variable integral PID control method. The same K_p, K_i, K_d parameters is selected ,and two PID control software program is written and run in MATLAB to compare the two PID control results[11].The step response output curves of this two kinds of variable integral PID control is shown in Figure 6 and Figure 7.

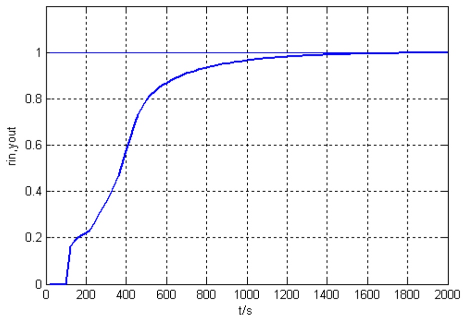

Figure 6.The step response curve of traditional variable integral PID control

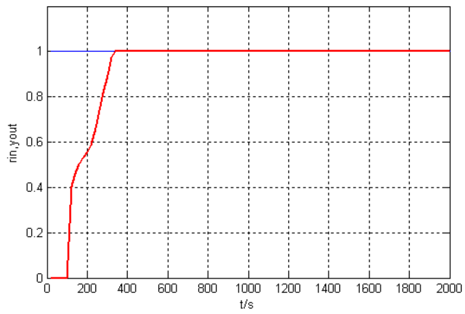

Figure 7.The step response curve of optimizational variable integral PID control

From the simulation results of the two PID controls, it can be seen that the response curve of the improved variable integral PID control has faster response time and high accuracy. The response speed of the common variable integral PID control is slower, adjusting time is longer ,but the steady accuracy is similar. Through comprehensive comparison,the response of the improved variable integral PID control is faster, the precision is higher and the control effect is better.

4.3.Experimental Study

In order to further value the correctness and availability, the above method is applied on the two-link tanks system base on the advanced process control experimental apparatus. It is also a typical computer control system. As shown in Figure 8.

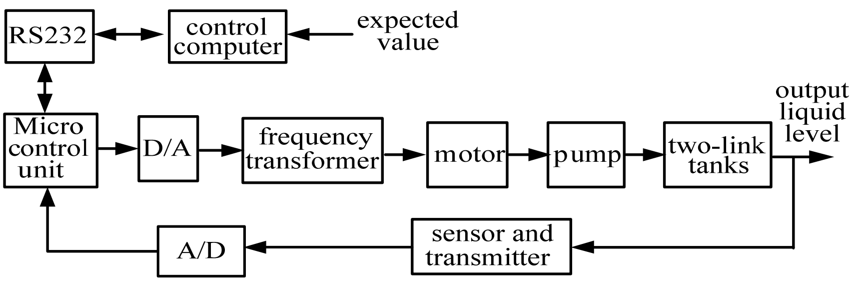

Figure 8. The liquid level control system block diagram of two-link tanks system

This experiment system working process is as follows:

The real-time output liquid level information from liquid level sensors is delivered to control computer by the MCU(Microprogrammed Control Unit) RS232 interface, and is compared with setting value in computer software,the result is error valule. Control computer runs PID control algorithm routine according to error valule size,and the control output result is delivered to frequency transformer by the MCU I/O interface.And then control the rotate speed of motor and pump to adjust liquid level in two-link tanks system.

The detailed experimental procedure is as follows:

Step1: program PID control algorithm routine according to design method in MATLAB, and then saves and embeds in configuration software in this experimental apparatus.

Step2: run THKGK software and access man-machine interface according to username and password.

Step3: set parameters and operate buttons in man-machine interface according to experiment instruction. As shown in Figure 9.

Figure 9.The human-computer interface of experimental control system

Step4: run the computer control system.

Step5: observe the real-time curve in man-machine interface window about 20 minute.

Step6: If the experimental results are not satisfactory,you may exit the system,and reprogramming throught changing the parameters.Repeat step2→step5.

According to the algorithm of designed method and above experiment step, the output curves of three PID control have deen get by adjustment parameter repeatedly and time after time experimenting，three PID control are respective traditional PID control,variable integral PID control and optimizational variable integral PID control.

Explain:Three PID controls experiment are run in the same status of control system and the same parameters of k_p , k_i and k_d .

The rusults are shown in Figure 10, Figure 11 and Figure 12.(note:The ordinate axis units of experiment curve are centimeter and abscissa axis units are minute)

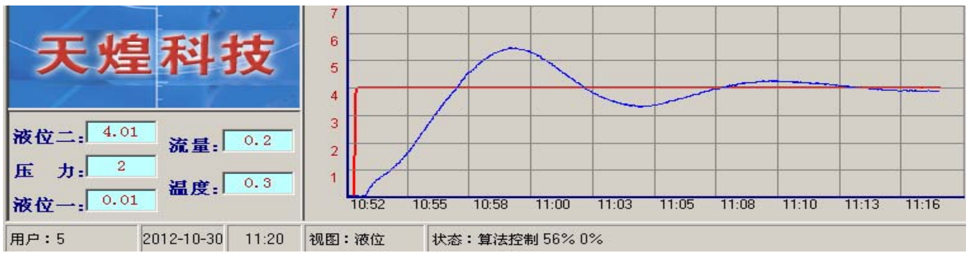

Figure 10.The experimental response curve traditional PID control(cm/min)

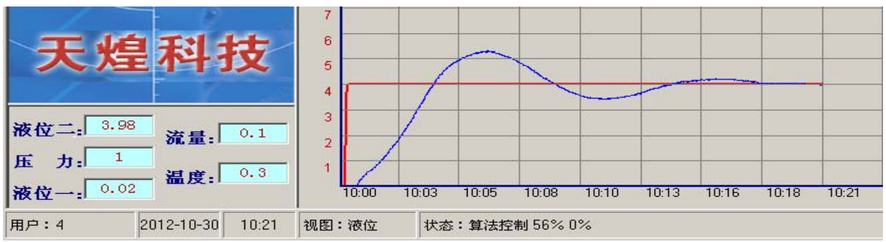

Figure 11.The experimental response curve of variable integral PID control(cm/min)

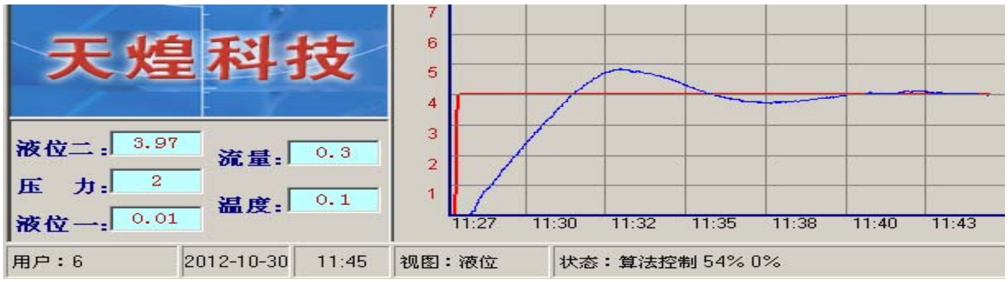

Figure 12.The experimental response curve of optimizational variable integral PID control(cm/min)

From the experiment results of three PID control, they can be seen that the output curve of the improved variable integral PID control has fastest response, least overshoot and higher accuracy. The response speed of the traditional PID control is slowest, biggest overshoot, adjusting time is longest and steady-state error is bigger. The response speed of the variable integral PID control is slower, adjusting time is longer, but the accuracy is similar with output curve of the improved variable integral PID control. Therefore the control effect of the improved variable integral PID control is best through comprehensive comparison.

At the same time, they can be also seen that the control effects of experiment results are worse compare with Simulink results. But they have similar variation law. Analysis of the reasons, the simulation results are received in a more ideal condition and the experimental results must meet the hardware conditions go on to achieve, but also have to consider the actual situation. It also indicates that the differences and relations between theory and practice.

5. Conclusion

PID control is a control strategy that has been successfully used over many years. And most cases, the integral increment is unchanging throughout the control process. The variable integral PID control is to change the integral increment according to the error size of the system; the purpose is not only to ensure the rapid response of the system, but also to improve the accuracy. The variable integral function is further optimized base on the variable integral PID control; the design method is improved in this paper. The simulation results and experiment application results of the design have shown that the optimized variable integral PID control further improve the system response speed and accuracy, and verify the correctness and superiority of the control method.

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