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Fuzzy PID Speed Control of Two Phase Ultrasonic Motor

Ma Qiujie, Shi Jingzhuo*
Henan University of Science and Technology
No.263 Kaiyuan Dadao, Luoyang 471023, China. Fax: +86-379-64231910
*Corresponding author, e-mail: sjznew@163.com

Abstract

Because of ultrasonic motor's time-variable nonlinearity, an online adaptive correction of PID control parameters based on fuzzy logic is presented. The special nature of ultrasonic motor's speed control is fully taken into account in designing fuzzy rules. The amplitude of driving voltage is used as the control parameter to realize the control method. The experiments indicate that the control characteristics are much better than that of PID controller.

***Keywords**: ultrasonic motor, speed control, fuzzy adaptive, PID*

1. Introduction

Because of ultrasonic motor's time-variable, nonlinearity, the strong coupling between control variables and other reasons, the motion's control performance is not easy to improve. As a kind of intelligent control strategy, a fuzzy controller of properly designed has strong robustness, and can weaken the impact of the object change to the control effect, so it is suiTable for nonlinear, time-varying objects, such as ultrasonic motor. But the tradeoff of parameters between robustness and control precision also exist in fuzzy control design, it is difficult to independent applied to the servo control occasions of high precision, thus we often combine fuzzy control with the traditional control method.

The fuzzy control is tried to apply to ultrasonic motor at home and abroad. The paper [1, 2], respectively combine the fuzzy control with neural network control and the sliding-mode control, and is use for ultrasonic motor control. In the paper [3], designed of the ultrasonic motor speed controller based on fuzzy logic was designed, and it is converted to PI control to improve the problem of poor steady-state performance of fuzzy control when the error is small. In the paper [4], the position control method that using a fuzzy controller to adjust the phase difference of two-phase voltage of the motor is presented, for the problem of the ultrasonic motor control dead-band. The paper [5] use fuzzy controller to adjust the frequency to realize speed control, and online correct fuzzy control rules based on genetic algorithms, so control algorithm is complex.

PID controller is designed to control the rotating speed of ultrasonic motor by adjusting voltage amplitude. Because of the time-varing and nonlinearity characteristics of ultrasonic motor, online adaptive correction of PID control parameters based on fuzzy logic is also designed. The special nature of ultrasonic motor's speed control are fully taken into account, applicative fuzzy rules is designed and amended by the actual test. The experiments indicate that the speed control performance has obvious improvement compared with traditional PID control alone.

2. Design of Fuzzy PID Speed Controller

2.1. Speed Control Characteristics Based on Voltage Amplitude Adjustment

In this paper, the traveling wave ultrasonic motor speed fuzzy PID control system structure is shown in Figure 1. Speed closed loop control achieved by the PID controller, fuzzy regulator is used for online correcting parameters of PID controller to improve the control performance.

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For achieving effective control of ultrasonic motor speed, the controlled variable can choose plus drive voltage amplitude, frequency or phase difference of motor; Thereinto, adjusting the amplitude of the voltage can achieve a good linearity, high precision of speed control. In this paper, we use the driving voltage amplitude as the controlled variable, that is the controlled variable of the output of the PID controller is the voltage amplitude of set value *Uref*, and through closed-loop control of the two - phase voltage amplitude of the inner loop to achieve the adjustment of the driving voltage amplitude. The input of fuzzy regulator is the ultrasonic motor speed error *e* and error variation *ec*, and the output is the incremental ΔK_p, ΔK_i, ΔK_d of PID control parameters K_p, K_i, K_d.

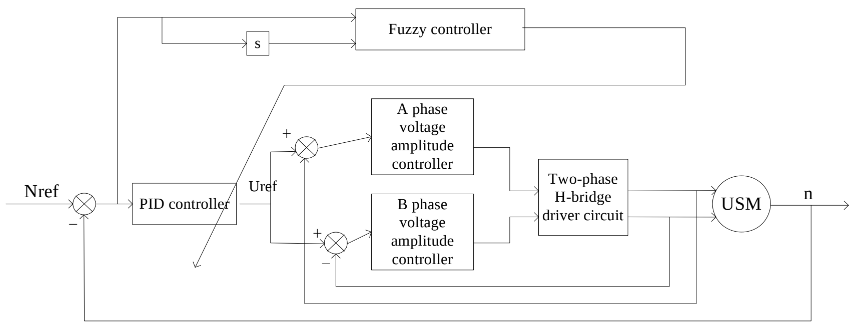

Figure 1. Structure of Fuzzy PID Speed Control System of Ultrasonic Motor

Using fuzzy rules to adjust the PID control parameters is a commonly control method. However, traveling wave ultrasonic motor speed control that base on voltage amplitude adjust has some running characteristics different from the conventional PID control, thus make the design of fuzzy regulator especially the design of the fuzzy rules are different from the common method obviously.

The process of the speed step response is starting from the motor static (speed is 0), for example, the output controlled variable of conventional PID control is generally starting from 0, and gradually increases under the controller action, and eventually reaches steady state value, and the steady-state value greater than the initial value 0. But because of special running mechanism of traveling wave ultrasonic motor, so it must be exerted high frequency high voltage to start. To ensure the USM normal start, the initial value of the set value *Uref* of the motor drive voltage amplitude usually larger, such as 300V, the initial value is usually greater than the value *Uref* that the motor steady-state operation needed after starting. Thus, the output controlled variable steady-state value of the PID controller is less than initial value, and the variation trend is different from the conventional PID control. On the other hand, also in order to ensure the USM normal start, the initial value of motor drive frequency must be set a high enough value to maintain the motor normal starting. However, if running in this higher frequency, the speed range is limited by adjusting the voltage amplitude achieved. If the speed set value is higher, we need to reduce motor drive frequency to an appropriate value. In order to reduce the response regulation time of the speed, the system is designed as follows, in the speed ascent stage after motor starting the frequency is reduced open-loop to the desired value as a fixed step. Thus, the speed closed loop PID control based on the voltage regulation along with the open-loop frequency reduction at the same time, have to increase the speed control complexity at the same time, also makes this PID control process is different from the conventional PID.

2.2. PID Control Algorithm

Figure 1 shows the PID controller uses incremental PID algorithm, the formula as follows.

$$\Delta u(k) = K_p * Ne + K_i * Nsp + K_d * (Ne - Nelast) \tag{1}$$

Here, *Nsp=Nref-n*, is the current motor speed error, *Nref* is a given speed, *n* is the actual speed. *Ne=Nsp-Nsp0* is the current speed error variation. *Nsp0* is the speed error on the previous moment. *Nelast* is the speed error variation of the previous moment.

2.3. Fuzzy Online Adjustment of PID Control Parameters

As mentioned above, the input of fuzzy regulator is the speed error *e* and error variation *ec*, and the output is the incremental ΔK_p, ΔK_i, ΔK_d of PID control parameters K_p, K_i, K_d. All of the fuzzy language value of five input and output variables is taken as 5: NB (negative big), NS (negative small), ZO (zero), PS (positive small) and PB (positive big). Membership function is selected triangular function, and each of variables membership function defined in the unit domain of discourse distribution are shown in Figure 2, Figure 3, respectively. The fuzzy inference method of the fuzzy regulator is MAX-MIN method, and the defuzzification method is Height method.

In order to make the actual values of input variables mapped to unit domain of discourse [-1,1], we need to set and quantify the quantization factors. In order to make these variables on different operating point position are not sensitive under the speed range, we consider the range of variation and characteristic of change of input variable values in actual control, and set the quantitative factor of speed error *e* as the speed set value *Nref*, and the quantitative factor of speed error variation is 10.

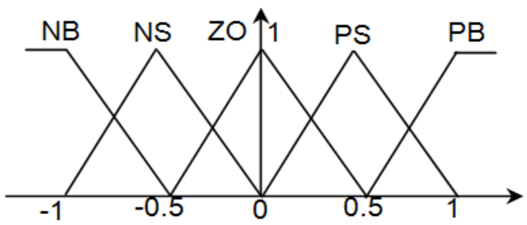

Figure 2. Membership Function Distribution of *e* and *ec*

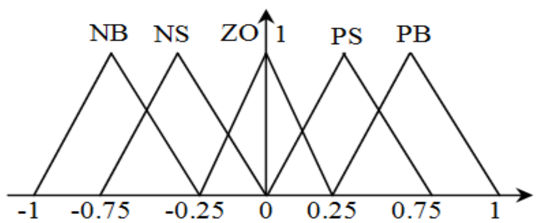

Figure 3. Membership Function Distribution of ΔK_p, ΔK_i, ΔK_d

The design of fuzzy control rules should take full account of the control particularity which is differ from conventional control aforementioned, in order to get expectant control effect. The ultrasonic motor drive voltage amplitude control variables have different effects in the rise and stabilization stage of the motor step response, in the rise stage, the bigger of the controlled variable the faster increased, but also easily cause overshoot.

Table 1. Fuzzy Rules of ΔK_p

e \ ec	NB	NS	ZO	PS	PB
NB	NB	NB	NS	NS	ZO
NS	NB	NS	NS	ZO	PS
ZO	NS	NS	ZO	PS	PS
PS	NS	ZO	PS	PS	PB
PB	ZO	PS	PS	PB	PB

Table 2. Fuzzy Rules of ΔK_i、ΔK_d

e \ ec	NB	NS	ZO	PS	PB
NB	PB	PB	PS	PS	ZO
NS	PB	PS	PS	ZO	NS
ZO	PS	PS	ZO	NS	NS
PS	PS	ZO	NS	NS	NB
PB	ZO	NS	NS	NB	NB

If the controlled variable is smaller, the response of the system will be slower, and in steady stage, the controlled variable's oversize can cause oscillation. When *e*<0, *ec*<0, the motor actual speed has exceeded the speed set value, the error and overshoot gradually increase, the control function of the voltage amplitude should try to reduce the overshoot. When *e*>0, *ec*>0,the motor actual speed has not yet reached the speed set value, and the error gradually increased, the function of the voltage amplitude should try to reduce reverse overshoot. When *e*>0, *ec*<0, the motor actual speed tends to the speed set value as soon as possible, that is the error should be eliminated as soon as possible. When *e*<0, *ec*>0, the motor actual speed has exceeded the speed set value, and the error is reduced. When the error and error variation decrease to zero, the system enters the steady state. At the same time, because of the K_p of PID controller can speed up the system response, integral action is mainly used to eliminate the static error of the system, and the derivative action can foresee the trend of the deviation variation, and produces advancing control action. The fuzzy rules for regulating ΔK_p, ΔK_i, ΔK_d are shown in Table 1 and Table 2 respectively. Thereinto, the fuzzy rules of ΔK_i is the same as ΔK_d, their variation trend are same, but the rangeability of ΔK_d is large.

3. Experimental Adjustment of Fuzzy Rules

In this paper, the design of DSP program realized ultrasonic motor fuzzy PID speed control, the experimental motor is *Shinsei USR60* two-phase traveling wave ultrasonic motor, the control circuit is H-bridge phase-shift PWM drive control circuit [6] based on DSP and CPLD, and the input power is DC12V.

As mentioned above, the design of the fuzzy regulator use the unit domain of discourse, its output needs to divide the corresponding output quantization factor to map to the actual value of ΔK_p, ΔK_i, ΔK_d. In Figure 4, the motor speed set value is 100r/min, the change process of speed step response in different output quantization factor contrast with the change process of controlled variable *Uref*, visibly, different output quantization factor makes different *Uref* change process, thereby, can produce impact to speed response process. Determine the quantitative factor of ΔK_p, ΔK_i, ΔK_d are 0.5, 1, 3.4, respectively, throught experiments adjustment.

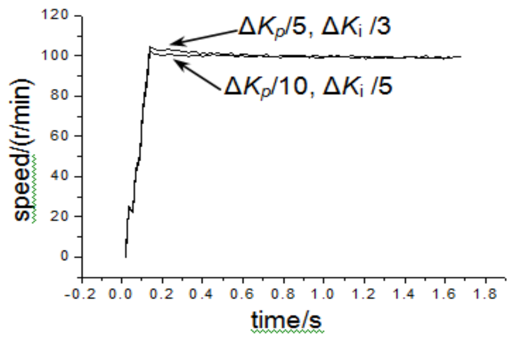

Figure 4. Step Response of Speed (Experimental results)

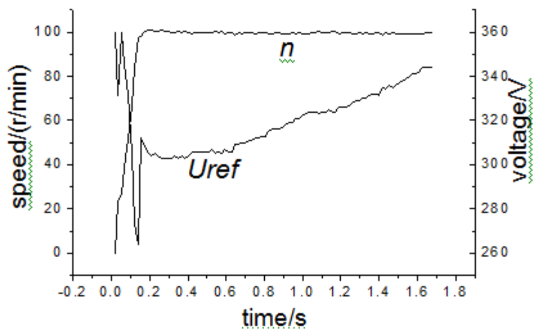

Figure 5. Step Response of Speed (Experimental results)

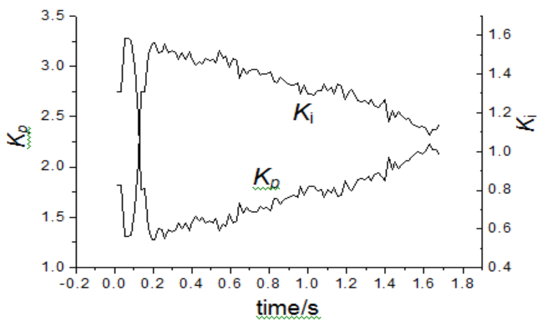

Figure 6. K_p and K_i Adjustment Process (Experimental results)

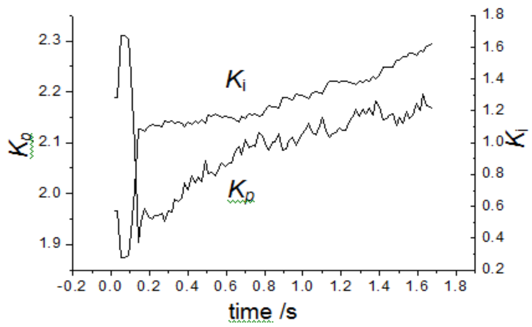

Figure 7. K_p and K_i Adjustment Process (Experimental results)

The fuzzy rules shown in Table 1 and Table 2 reflect the expectations of design process. The rules need to trim as the actual application effect. Figure 5 shows the rules shown in Table 1 and Table 2, the speed step response when the motor set value speed is 100r/min, and the change process curve of controlled variable *Uref*, Figure 6 shows the corresponding adjustment process curve of K_p, K_i, the adjustment process is basically in line with expectations (adjustment process is similar, in order to make the graphics clearer, not shown in the Figure). But Figure 5 shows that , after the speed reached steady state , the motor speed reduces slowly and deviates from set value; Referring to Figure 6, it shows the adjustment process of control parameter, and this is mainly because of K_i gradually reduce in steady state, and the control effect weakened. Analysis of fuzzy adjustment process data shows the dominant rule which lead to K_i gradually reduce in steady state is the following fuzzy rule in Table 2.

if e=ZO and ec=PS then k_i=NS

Adjust the rule as follows:

if e=ZO and ec=PS then k_i=ZO

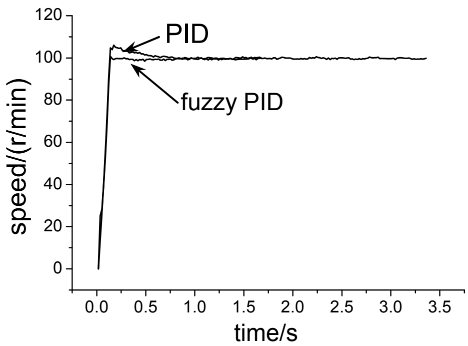

Figure 8. Step response of speed
(Experimental results)

The new adjustment processes of K_p, K_i are shown in Figure 7, the corresponding speed response curve are shown in Figure 8, and above problems disappear. Figure 8 at the same time shows the effect of the speed control when using fixed parameters PID control, PID parameters are the same as the initial value of PID parameter of fuzzy PID control. Visibly , in the premise that the fuzzy PID keep the speed to fast-track varying set value, when overshoot is lowered to 0, the control performance is better than it of the PID controller.

4. Conclusion

The special nature of ultrasonic motor's speed control are fully taken into account in this paper, a online adaptive correction of PID control parameters based on fuzzy logic is designed, to deal with the time-varying nonlinear of system. The experiments indicate that the fuzzy rules of special design achieved the expectant control parameter adjustment process. Compared with the PID controller, the control performance has obvious improving.

Acknowledgements

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