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SIMULATION STUDY ON FUZZY PID CONTROLLERfor DC motor based on DSP

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Abstract*-For the nonlinearity and time-varying model of DC motor speed control system,the non-optimum problems are brought by offline setting parameters of traditional PID controller,an improved fuzzy PID controller algorithm based on DSP is proposed.With current feedback error and error change rate as input variables of fuzzy controller,PID parameters are optimized on-line by the fuzzy PID controller with self- setting parameters.With DSP development system as simulation platform,separately excited DC motor transfer function transformation as difference equation,a digital closed-loop simulation system of separately excited DC motor based on fuzzy PID controller is set up.On-line simulation is carried out by DSP high speed operation ability.The output waveforms of system generated by traditional PID controller and fuzzy PID controller are observed.CCS(Code composer Studio) 2.0 simulation tests show that an improved fuzzy PID controller realizes zero overshot essentially,the rise time and adjusted time of system step response is smaller than traditional PID controller's.System proformances are markedly higher than traditional PID controller by applying a fuzzy PID controller to the separately excited DC motor speed system.

Keywords-Fuzzy PID; DSP; speed governing system; parameter setting.

I. INTRODUCTION

The digital PID controller are widely adopted in the DC motor speed control system.Many improved digital PID control methods were applied on the basis of PID controller,such as differential linearity PID control,integral separating PID control,the PID control with dead zone,fuzzy PID control and neural network PID control.Among them,traditional digital PID controllers are most widely used,but trial-and-error methods are adopted in the selection of the controller parameters so that it is difficult for digital-PID parameters to be set,its performances is non optimital and control accuracy is hard to be improved farther[1,2].

A fuzzy PID controller is suited for the controlled objects whose mathematical models are uncertain.It is simple to realize and insensitive to changes of process parameters.But the fuzzy PID controller needs expert's experiences to establish fuzzy look-up tables.A neural network PID controller has usually self-learning and self-adapting ability,but it is difficult to implement because of the complexity of algorithms and the lack of much data.

In the paper [3],a fuzzy PID controller is applied to the steam temperature control.The designed fuzzy PID controller has stronger adaptive ability by adjusting scaling factors on-line and optimizing control process.However,the control precision and stability are not yet optimized further because there is a dead zone when controlled variables are smaller deviation range.In the paper [4-6],a neural network learns on-line fuzzy control rules,tunes PID parameters by optimization,solving the problems of PID controller parameter optimization.But the control algorithms are very complicated so that it is difficult to implement on projects.In the paper [7],an fuzzy PI controller is applied to DC motor speed governing system.The fuzzy controller designed has better static and dynamic performances,but fuzzy information is simple so that the control precision and dynamic quality are not optimized.In the paper [8-11],by a method of combining hardware and software, the amount of computation of PID control algorithm is reduced,but fuzzy look-up tables occupy bigger storage spaces.

An improved fuzzy PID algorithm is proposed that is on basis of traditional PID algorithm.The current-feedback error and the change rate of error are used as the intput of the fuzzy controller with parameter auto-tuning without establishing bigger look-up tables.PID parameters are set by itself on line on the different error and the change rate of error.The control variable is rapidly calculated using the strong computation ability of DSP.As soon as the controlled objects vary,PID parameters vary.DSP development system is used as simulation platform to make up fuzzy PID control module.Tests show that the control quality of system has good dynamic indexes that essentially achieves zero overshot,which has better anti-interference and adaptability than the tranditional PID controller.The self adaptive problems of PID parameters setting is solved fundamentally.

II. SEPARATELY EXCITED DC MOTOR SPEED GOVERNING SYSTEM CONTROL MODEL

A diagram of separately excited DC motor speed system based on fuzzy PID controller made up with TMS320LF2407 from TI. is shown as Fig.1.

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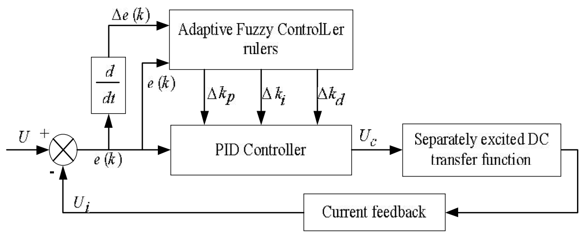

Fig.1 A diagram of separately excited DC motor speed system based on fuzzy PID controller

The current-feedback error (e) and the error change rate (Δe) are used as the inputs of an fuzzy controller,then fuzzified as E and Ec.The control output is generated by fuzzy reasoning and decision that is defuzzifid as U_c to control a separately excited DC motor.PID parameters are set by itself on line making use of fuzzy rules for different e and Δe to gain fairly good dynamic performance.

The transfer function of separately excited DC motor is followed on the starting without load,i.e when T_L=0.

$$G(s)=\frac{\Omega(s)}{U(s)}\Big|_{T_L=0}=\frac{C_T'}{L_aJs^2+(L_aB+JR_a)s+R_aB+C_e'C_T'} \quad (1)$$

In equation (1), $C_e'=30C_e\Phi/\pi$, $C_T'=C_T\Phi$, $C_T\Phi$=9.55$C_e\Phi$, $C_e\Phi=(U_e-I_eR)/n_e$.

U_e is armature rated voltage,I_e is armature rated current,R is armature resistance,J is Motor rotational inertia, n_e is rated speed,B is the viscous damping coefficient of motor and load.L_a is armature inductance,Φ is magnetic flux,C_T is torque coefficient.

By z-transformation,the equation (1) was transformed to be the differential equation as follow:

$$y(k)=Y_1y(k-1)+Y_2y(k-2)+Y_3x(k-1) \quad (2)$$

Where

$$Y_1=2e^{-\frac{L_a+JR}{2L_aJ}T}\cdot\cos\{\frac{[4L_aJ(RB+C_e'C_T')-(L_aB+JR)]^{\frac{1}{2}}}{2L_aJ}T\} \quad (3)$$

$$Y_2=2e^{-\frac{L_a+JR}{2L_aJ}T} \quad (4)$$

$$Y_3=\frac{C_T'}{2}\cdot e^{-\frac{L_a+JR}{2L_aJ}T}\cdot[4L_aJ(RB+C_e'C_T')-(L_aB+JR)]^{\frac{1}{2}} \quad (5)$$

In equation (5), T is sampling cycle.

III. FUZZY PID CONTROLLER DESIGN PRINCIPLE

The fuzzy PID controller design principle is that fuzzy reference rules are called on the number of error signals to determine dynamically PID parameters for the control effect improved.

Suppose input error is e,deviation change rate is Δe,K_p is the proportional coefficient of PID controller,K_i is integral coefficienti,K_d is differential coefficient.To fuzzify these continuous variables to discrete variables,the equations (6) and (7) are used to discretize continuous universe to integer universe.

$$b=q[a-\frac{1}{2}\cdot(x_L+x_H)] \quad (6)$$

$$q=\frac{2n}{x_H-x_L} \quad (7)$$

Where a is a number of the continuous universe X=[x_L,x_H],b is an integer of the integer universe N corresponding to a,q is a scaling factor that is used when determinated quantities are fuzzified in fuzzy control.

The value ranges of integer universe N are N = {±6,±5,±4,±3,±2,±1,0}.On this universe,fuzzy linguistic variables are set as {*NB,NM,NS,ZO,PS, PM,PB*},namely representing{negative large,negative,negative small,zero, positive small,middle,positive big}.If e,Δe,ΔK_p,ΔK_i,ΔK_d obey triangle membership function curve distribution,the corresponding curve is shown as Fig.2.

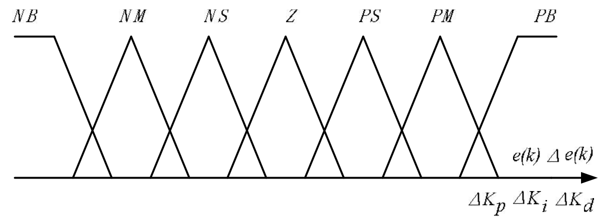

Fig. 2 Triangle membership function distribution graph

To avoid compositional operations of relationship matrix in real-time control,all possible inputs and outputs are calculated off-line to form a control table that is represented in the form of integers shown as Table 1,which *PB* takes the values from 5 to 6,*PM* from 3 to 4,*PS* from 1 to 2,*ZO* takes the value 0.The value ranges of *NB*,*NM*,*NS* are same.

Because the control quantity that is inferenced fuzzily from the control table is also an fuzzy quantity,it must be defuzzifid for output.If the integer universe is N=[-n,+n],the continuous universe is X=[x_L,x_H],the reference formula of defuzzification is shown as equation (8).

$$a=k[b+\frac{n(x_L+x_H)}{x_L-x_H}] \quad (8)$$

Where a is a number of the continuous universe X=[x_L,x_H],b is an integer of the integer universe N=[−n,+ n] corresponding to a,k is a scaling factor when fuzzy quantities is defuzzifid [12],which the reference computing formula is shown as equation (9).

$$k=\frac{[x_H-x_L]}{2n} \quad (9)$$

Where k is the scaling factor when fuzzy quantities is defuzzifid [12].In actual application,the defuzzifying scaling factors of input error e and deviation change rate Δe for fuzzy PID controller is determinated by trial and error.

The design principle of fuzzy control rules are described as follows:

When errors are bigger,in order to eliminate deviation and obtain better response times,it should takes bigger value K_p and smaller value K_d ,as well as in order to avoid the system occur overshot,it should limites the integral effect,usually takes K_i as zero.

When errors are medium,it should takes smaller value K_p to make overshot of system response smaller,also because the impact of value K_d is larger on system,it should takes smaller value K_d and appropriate K_i.

When errors are smaller,it should takes smaller value K_p and bigger K_i to make system response better stability, as well as in order to avoid the oscillating nearby the balance point of system,it should takes appropriate value K_d.

IV. SIMULATION DESIGN OF FUZZY PID CONTROLLER

The parameters of the separately excited DC motor are used in the simulation test that the rated power P_e is 1.2KW,rated voltage U_e is 24V,rated speed n_e is 2600r/min.Thereby it calculates that rotational inertia J is $0.0032\text{kg}\cdot\text{m}^2$, armature inductance L_a is 0.015H,electrical time constant T_a is 0.0076s,torque coefficient C_T is 0.0796N·m/A,potential coefficient C_e is 0.0083V·s/rad, armature resistance R is 0.0375Ω,mechanical time constant T_m is 0.0189s, viscous damping coefficient B is neglected.The associated parameters are substituted into the equation (3) to (5) to get the coefficients of the differential equation (2) for the separately excited DC motor,which Y1=0.001096,Y2= -1.854×10^{-6}, Y3=119.9.

On the condition that the maximum over-shoot is less than 7%,adjusting time is less than 50ms,the better parameters of fuzzy PID controller are determined by trial and error that K_p is 0.9,K_i is 0.1,K_d is 0.01.For dynamic optimization,the variation range of PID parameters are set to K_p values from 0 to 1,K_i values from 0 to 0.5,K_d values from 0 to 0.09.

The fuzzy PID algorithm is implemented on DSP platform,the main program calls the control algorithm subroutine for the fuzzy PID to compute the control variable $U_c(k)$,which is as the input of differential equation (2) for the separately excited DC motor.Lastly the differential equation for the separately excited DC motor is executed to cause the response of system output.The main program flow chart is shown as Figure 3.The subprogram flow chart is shown as Fig. 4.

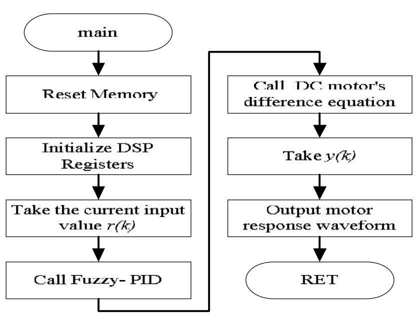

Fig.3 The main of Fuzzy PID control algorithm flow chart.

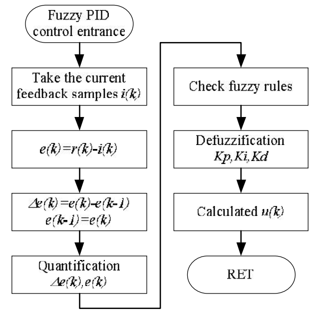

Fig.4 The subprogram of Fuzzy PID control algorithm flow chart

V. 5. SIMULATION TEST

The fuzzy PID controller is simulated and designed on a DSP simulation platform that is consist of a DSP emulation and a TMS320LF2407 DSP experiment board.For the DSP clock frequency is 40MHz and the step input value is 31,the display effects of output waveforms are shown as Fig.5-6 in CCS generated by the commands just as view/graph/time/frepuence after the traditional PID algorithm and the fuzzy PID algorithm are executed by DSP respectively.It is seen from Fig.5 that a larger oscillation and some overshoot occur when the moter starts for the small constant time and inertia.Although the differentiation element of PID controller can improve the dynamic performance of system and speed the system reponse,the adaptivity of the integration element is weakened.When the integration effect declines,the static error of system output can occur.It is seen from Fig.6 that the fuzzy PID controller can eliminate the static error of system output fastly after the system enters the steady-state to realizes zero overshot.The rise time and adjustment time of system step reponse is smaller than the traditional PID controller's,which has better control quality.

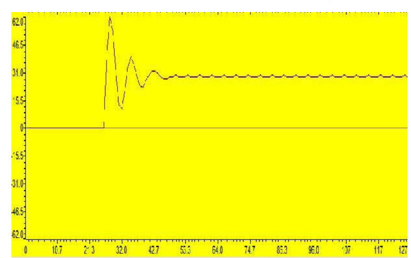

Fig.5 The step response of system with traditional PID

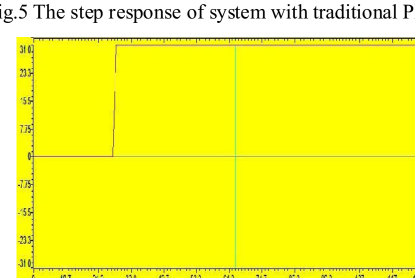

Fig.6 The step response of system with fuzzy PID

VI. 6. CONCLUSIONS

The improved fuzzy PID controller algorithm based on DSP realizes the on-line optimization of PID parameters,which is featured by the high operational precision and fast response.Simulation experiments show that adjustment time of system step reponse is short and zero overshot.It provides a effective mean for the optimal control of DC motor based on DSP.

REFERENCES

[1] FU Xiao-ling;JIANG Bo.Design of Digital PID Control Based on DSP.Moderm Electronics Technique[J],2007,7(246),PP:129-131.

[2] OU YANG Lei; HUANG You-rui. PID Controller Based on Fuzzy RBF Neural Network and Its Application.Computer Engineering[J].2008,34(22),PP:231-233.

[3] NIU Pei-feng;REN Juan;WANG Shuai. Emulation Study on PID Type Adaptive Fuzzy Control in the Main Steam Temperature Control of Boilers.Thermal Power Generation[J],2008,06(24),PP:24-27.

[4] ZHANG Cai-xia;ZHANG Zhi-fei. Application of Fuzzy Neural Network PID for Three tan Water.Moderm Electronics Technique[J],2009,10(297),PP:137-139.

[5] ZHANG Yong-jun;WANG Hang-yu.Design of Temprature Fuzzy PIDControl Based on BP Neural Network.Moderm Electronics Technique[J],2008,7(270),PP:133-135.

[6] MA Ning.The Application of ANFIS-PID in the Power Plant Superheated Steam Temperature Control.Techniques of Automation and Application[J],2008,27(4),PP:31-33.

[7] WANG ling;LIU Wei-guo.Simulation of BLDCM Speed Control System Based on Fuzzy PI Control Method.Computer Simulation[J],2009,26(10),PP:186-189.

[8] ZHOU Zhen-yuan.Application of Fuzzy-PID Control in Automatic Photoelectric Abb Finishing Apparatus.Micromotors Servo Technique[J],2009,37(10),PP:30-32.

[9] ZHUANG Zong-bao;ZHOU Hong-fu.Fuzzy System DSP based for DC Motor Speed Control . Moderm Electronics Technique[J],2008,10(273),PP:57-60.

[10] YU jin-jin.AC motor fuzzy PID control system Based on DSP.Popular Science & Technology[J],2010,12(136),PP:99-100.

[11]LI Quan-fu;WAN Yan-hui;GUO Hua.Study on Fuzzy PID Control of Electrical Control Actuator Based on DSP.Micromotors Servo Technique[J], 2007,40(12),PP:28-30.

[12] WANG Xiao-pin;DAI Guo-jun;ZEN Hon.Study on Performance of CRI Arithmetic in Fuzzy Reasoning.Computer and Digital Engineering[J],2006,34(3),PP:45-47.