Fuzzy Logic based Thickness Control System and Its Simulation

Xing-Yuan XU[1], Zhan-Wei BU[2], Yuan-Li Cai[1], Xiao-Yan XU[1]
1.Dept. of Automatic Control, Xi'an Jiao Tong University, Xi'an 710079,China,Email: xuxingyuan2003@126.com
2.Luoyang Institute of Science and Technology, Luoyang 471023,China,Email: BZW167@LIT.EDU.CN

***Abstract*—In general, the rolling mill uses PID method to control the plate thickness. Performance of the PID controller relies on the plant model, however it is difficult to establish the precise model of hydraulic servo system due to its uncertainties. Fuzzy control does not need the precise model, so a fuzzy PID controller is designed. In this paper, a mathematical model of the rolling mill in ideal circumstance is derived, and then the fuzzy PID controller is presented and extensively evaluated by model-based simulation. The influences of parameters perturbation and external disturbances were taken into account. Simulation results show that the anti-interference capability and robustness of the fuzzy PID controller are much better than the traditional PID scheme.**

Keywords-fuzzy control; thickness control; PID; robustness

I. Introduction

With the development of end products, higher quality of plate and strip supplied by iron and steel enterprises are requested in terms of thickness and shape tolerance, thereby how to improve the precision of products is always a hot research topic in metal processing field. Rolling process involves several control systems, such as thickness, speed, tension, shape et al, accuracy of the automatic control plays a significant impact on products quality [1]. At the present time, most of the rolling mill use PID control which relies on plant model [2]. Although the adaptive control can identify characteristic parameters of the plant online, but its accuracy depends on the precise of the distinguishing model. And also it is actually extremely difficult or even impossible to do so for the complexity of rolling process [3].

In general, improving of the performance of the plate and strip is usually through adjusting the roller position, automatic position control is the key aspects that affect the accuracy of products. Most mills are now using hydraulic servo system. Hydraulic servo system has many uncertainties [4], such as parameter perturbations, external disturbance and dead-zone due to the nonlinearity of servo valve, which makes hydraulic servo system a nonlinear uncertainty system.

In recent years, Yen J S et al applied model based adaptive control to the hydraulic servo system [5], it is performed perfectly based on linear model, but it is not fit for nonlinear model. SHA Dao-hang et al put forward multilayer forward feed network control [6], with the drawback of slow learning rate, and the dependence of the learning results on training steps and sequence of input data. Lee D et al bring about an adaptive fuzzy controller with nonlinear compensation and a switching control strategy to regulate molten steel level [7]. Hong K S et al have proposed a structure variable controller to molten steel level control of twin-roll strip casting[8][9].Most of the control methods proposed in recent years remain in theoretical research, few applied in practical. The author designs a fuzzy PID controller, and lots of simulation based on the model of $\Phi250/\Phi750\times800$ rolling mill has been done. Simulation results indicate that the fuzzy controller has good performance and strong robustness.

II. Mathematical Model of Plant

Position control system is the basic stage of the hydraulic servo system which controls the location of cylinder, thereby controls the roll gap. We hope that position control system has enough hydraulic pressing speed and better stability, that is, with a larger open-loop magnification and closed-loop bandwidth [2].

Position control system includes controller, electro-hydraulic servo valve, cylinder and position feedback, as is shown in Fig.1.

In Fig.1, ΔY_0 is position given, ΔU is position error, ΔI is current change, ΔQ_L is flow change, ΔY is position change.

Electro-hydraulic servo valve and cylinder can be considered as the generalized plant.

Strictly speaking, electro-hydraulic servo valve is a nonlinear device which can be regarded as a secondary-order oscillation link [1].While usually electro-hydraulic servo valve is regarded as a ratio regulator; in fact, it is inconsistent with the reality. In this paper, electro-hydraulic servo valve is regarded as secondary-order oscillation link, the transfer function is shown using (1).

$$\frac{\Delta Q_L}{\Delta I}=\frac{K_V}{\frac{1}{\omega_v^2}s^2+\frac{2\delta_v}{\omega_v}s+1} \quad (1)$$

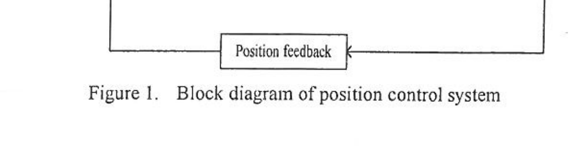

Figure 1. Block diagram of position control system

978-0-7695-3887-7/09/$26.00 ©2009 IEEE

The cylinder can be regarded as an integral link and a second-order oscillation link [3], the transfer function is shown below using (2).

$$\frac{\Delta Y}{\Delta Q_L}=\frac{K_h}{s(\frac{1}{\omega^2}s^2+\frac{2\delta}{\omega}s+1)} \qquad (2)$$

From (1) and (2), we can get transfer function of the plant, shown in (3).

$$G_p(s)=\frac{K_v K_h}{s(\frac{1}{\omega_v^2}s^2+\frac{2\delta_v}{\omega_v}s+1)(\frac{1}{\omega^2}s^2+\frac{2\delta}{\omega}s+1)} \qquad (3)$$

Table I is the operating parameters of $\Phi250/\Phi750\times800$ four roller reversing mill, the type of electro-hydraulic servo valve is QDY-D32.Substitute the parameters in table I to formula (3), we can get the mathematical model of the plant.

$$G_p(s)=\frac{14.4}{1.74\times10^{-13}s^5+2.06\times10^{-9}s^4+3.37\times10^{-6}s^3+2.28\times10^{-3}s^2+s} \qquad (4)$$

III. FUZZY ADAPTIVE CONTROL

Combining PID control theory and fuzzy theory, through continuous detection of the error E and error change rate EC in every moment, through regulating the parameters (K_p, K_i, K_d) online to make the plant possesses a good dynamic and static characteristic, which is the fuzzy adaptive PID control [10] [11].So therefore a two-dimensional fuzzy PID controller is adopted in this paper, its structure is shown in Fig.2. K_p, K_i, K_d are proportion ratio, integral ratio, differential ratio respectively. $\Delta K_p, \Delta K_i, \Delta K_d$ are the change of K_p, K_i, K_d respectively. Designing steps of the fuzzy controller will be introduced in the following sections.

The input and output variables of a fuzzy system are the linguistic variables because they take linguistic values. The input variables are E and EC. The output variables are $\Delta K_p, \Delta K_i, \Delta K_d$.The universe of discourse of the linguistic variable E and EC is supposed to be [-3, 3], and the output variable ΔK_p is [-0.3, 0.3], ΔK_i is [-0.06, 0.06] and ΔK_d is [-3, 3]. Each of the linguistic variables is assumed to take seven linguistic sets defined as negative big(NB), negative middle(NM), negative small(NS), zero(ZO), positive small(PS), positive middle(PM), positive large (PB). The linguistic sets are described by their membership functions as shown in Fig.7.

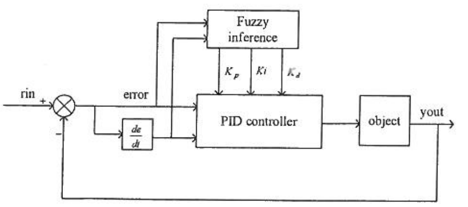

Figure 2. Structure of fuzzy adaptive controller

TABLE I. $\Phi250/\Phi750\times800$ OPERATING PARAMETERS

Parameter	value
Cylinder diameter	d=40cm
Cylinder area	A= $(\pi/4)d^2$ cm^2
Work oil high	h=1cm
Moving parts weight	G=6700kg
Rated no-load flow	Q_0=533 cm^3/s
Rated Current	I_0=0.03A
Cylinder damping coefficient	δ =0.1～0.2
Cylinder natural frequency	$\omega=2600\sqrt{\frac{A}{Gh}}$
servo valve damping coefficient	δ_v=0.7
servo valve natural frequency	ω_v=680 1/s
Feedback coefficient	K_f=100 V/cm
Servo Magnification coefficient	$K_v=Q_0/I_0$
cylinder magnification coefficient	$K_h=1/A$

In practice,the membership functions of the linguistic sets (NB,PB) are suggested to follow normal distribution, the other membership functions for linguistic sets(NM,NS,ZO,PS,PM) are suggested to be triangular .

The core work of fuzzy PID controller is to establish a proper fuzzy rule. Fuzzy rules for the parameters ΔK_p, ΔK_i, ΔK_d of $\Phi250/\Phi750\times800$ rolling mill is shown in table II,tableIII and table IV.

Based on the fuzzy rules given, PID parameters (K_p, K_i, K_d) can be automatically adjusted to the best. Fuzzy control rules and related information (such as evaluation index, initial PID parameters etc) will be put into the computer as a pre-knowledge, by applying fuzzy reasoning algorithm to develop fuzzy control matrix of PID, based on the input of the system, through querying fuzzy control matrix to find the compensation parameters(ΔK_p , ΔK_i , ΔK_d), then substituting them into (5)-(7), we get K_p, K_i and K_d. Tuning of the PID control parameters must consider the difference of the membership function and their mutual relationship and also the parameters (K_p 、 K_i 、 K_d), identify the fuzzy relationship between control parameters K_p, K_i K_d and E, EC. The work flow chart Online is shown in Fig.3.

TABLE II. FUZZY RULES TABLE OF ΔK_p

ΔK_p		EC						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PB	PB	PM	PM	PS	ZO	ZO
	NM	PB	PB	PM	PS	PS	ZO	NS
	NS	PM	PM	PM	PS	ZO	NS	NS
	ZO	PM	PM	PS	ZO	NS	NM	NM
	PS	PS	PS	ZO	NS	NS	NM	NM
	PM	PS	ZO	NS	NM	NM	NM	NB
	PB	ZO	ZO	NM	NM	NM	NB	NB

TABLE III. FUZZY RULES TABLE OF ΔK_i

ΔK_i		EC						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	NB	NB	NM	NM	NS	ZO	ZO
	NM	NB	NB	NM	NS	NS	ZO	ZO
	NB	NB	NM	NS	NS	ZO	PS	PS
	ZO	NM	NM	NS	ZO	PS	PM	PM
	PS	NM	NS	ZO	PS	PS	PM	PB
	PM	ZO	ZO	PS	PS	PM	PB	PB
	PB	ZO	ZO	PS	PM	PM	PB	PB

TABLE IV. FUZZY RULES TABLE OF ΔK_d

ΔK_d		EC						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PS	NS	NB	NB	NB	NM	PS
	NM	PS	NS	NB	NM	NM	NS	ZO
	NS	ZO	NS	NM	NM	NS	NS	ZO
	ZO	ZO	NS	NS	NS	NS	NS	ZO
	PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
	PM	PB	NS	PS	PS	PS	PS	PB
	PB	PB	PM	PM	PM	PS	PS	PB

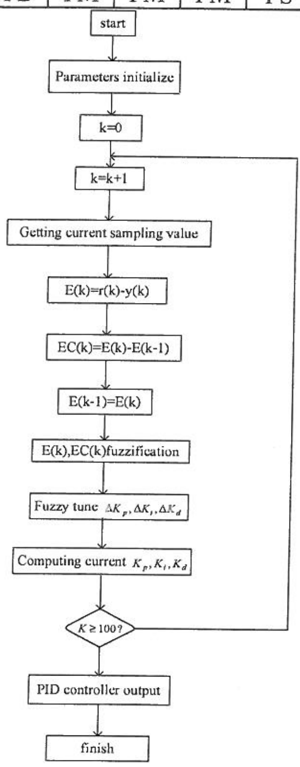

Figure 3. Flow chart of online self-tuning

$$K_p = K_p^{'} + \Delta K_p \tag{5}$$

$$K_i = K_i^{'} + \Delta K_i \tag{6}$$

$$K_d = K_d^{'} + \Delta K_d \tag{7}$$

IV. SIMULATION AND ANALYSIS

For $\Phi 250/\Phi 750 \times 800$ rolling mill, we have got its plant model:

$$G_p(s) = \frac{14.4}{1.74\times10^{-13}s^5 + 2.06\times10^{-9}s^4 + 3.37\times10^{-6}s^3 + 2.28\times10^{-3}s^2 + s}$$

Comparing results about the step response of fuzzy PID control proposed in this paper with the traditional PID control are shown in Fig.4, and a disturbance of 1.0 in the 60th sampling time has been added to the output of the controller.

From Fig.4, fuzzy adaptive PID control has not overshoot in rising process. And also fuzzy adaptive PID controller has better anti-interference ability and the adaptive adjustment process K_p, K_i K_d are all shown in Fig.5. The initial value of K_p, K_i K_d were set to 8, 0.0, 0.0 respectively, with steady-values are 8, 0, -1.

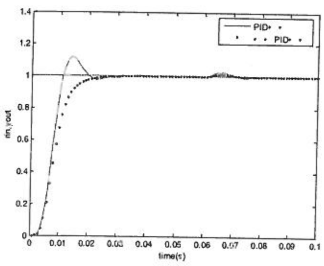

Figure 4. PID control and fuzzy PID control system step response

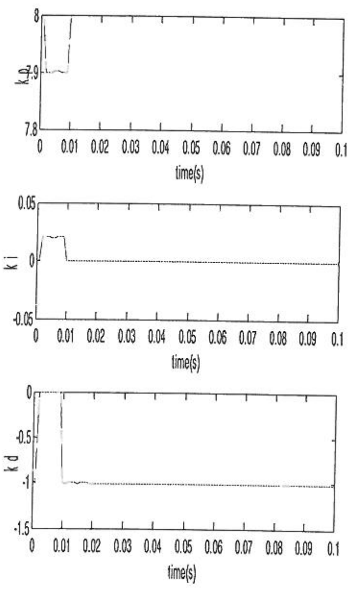

Figure 5. the adaptive adjustment process of K_p, K_i, K_d

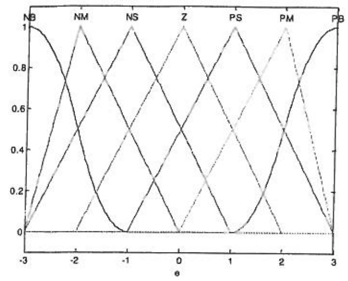

Figure 6. the membership function of E and EC

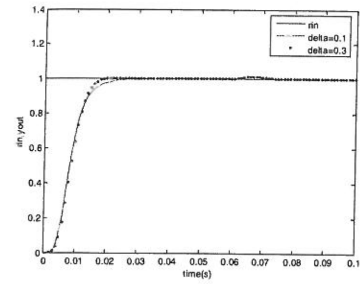

Figure 7. Step response of fuzzy PID control when δ =0.1 and δ =0.2

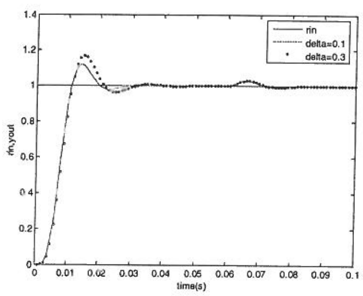

Figure 8. Step response of traditional PID control when δ =0.1 and δ =0.2

Due to the parameter perturbation in position control system, so it is important to consider whether the system output can track the input well when the parameters of the control plant change, which is to say whether the system is robustness. The robustness of the fuzzy controller is verified through changing cylinder hydraulic damping coefficient δ .Generally δ adopts $0.1 \sim 0.2$, we adopts δ =0.1 first and δ =0.2 second .The initial value of K_p, K_i, K_d keep the same .The simulation results are shown in Fig.7, Fig.8.

$$G_p(s) = \frac{14.4}{1.74\times10^{-13}s^5 + 2.85\times10^{-9}s^4 + 4.12\times10^{-6}s^3 + 2.64\times10^{-3}s^2 + s} \quad (8)$$

We can see from Fig.7 and Fig.8 that when δ changes from 0.1 to 0.2, the step response of traditional PID control system have an obvious increase of overshoot, but fuzzy adaptive control system changes little, maintaining good control performance ,Which means that the fuzzy adaptive controller has better robustness than the traditional PID controller.

V. CONCLUSION

Mathematical model of position control system of $\Phi250/\Phi750\times800$ rolling mill is presented, based on the traditional PID controller, a fuzzy adaptive controller was developed and simulation was carried out. The influence of disturbance and parameter perturbation is taken into account during the simulation, simulation results prove the designed fuzzy adaptive controller has better performance, better anti-interference capability and better robustness than the traditional PID controller. As hydraulic pressure drop has high demands for fast control, so how to simplify the fuzzy control rules, improve fuzzy reasoning algorithm and reduce the computation, needs further research in the future. In addition, although the fuzzy PID controller have good robustness when δ changes, but hydraulic servo system has many uncertainties, and control system for position , speed, tension, temperature et al have a very strong coupling relationship, hence in practical ,the fuzzy controller has to consider all kinds of factors that may be deeply coupled.

REFERENCES

[1] Anders G Carlstedt,Olov Keijser,"Modern Approach to Flatness Measurement and Control in Cold Rolling,"Iron and Steel Engineer,1991,68(4),pp.34-37.

[2] Ikuya Hoshno,Masateru Kawai,Misao Kokubo,"Observer-Based Multivariable Flatness Control of the Cold Rolling Mill,"Perprint of the 12th IFAC World Congress, Vol.6,Sydney,Australia,1993,pp.149-156.

[3] SHI Wei-xiang,DU Yan-ting,"New Development of Electro-hydraulic Servo System Adaptive Control," Machine Tool & Hydraulics,1995,(1),pp.1-7 (in Chinese) .

[4] DONG Min, LIU Cai, "Design of Fault Diagnosis Observer for HAGC System on Strip Rolling Mill,"Journal of Iron and Steel Research,International,2006,13(4),pp.27-31.

[5] Yun J S,Cho H S,"Application of an Adaptive Model Following Control Technique to a Hydraulic Serve System Subjected to Unknown Disturbances,"Journal of Dynamic Systems,Measurement and Control,1991,113(3),pp.479-486.

[6] SHA Dao-hang,YANG Hua-yong, "Research on Neural Network Control for Electrohydraulic Position Servo System Subjected to Load Disturbance,"Machine Tool & Hydraulics,1997,(2),pp.15-17 (in Chinese) .

[7] Lee D, Lee J S, Kang T,"Adaptive Fuzzy Control of the Molten Steel Level in a Strip-Casting Process,"Control Engineering Practice,1996,4(11),pp.1511-1520.

[8] Hong K S , Kim J G , Tomizuka M,"Control of Strip Casting Process:Decentralization and Optimal Roll Force Control,"Control Engineering Practice,2001,9(9),pp.933-945.

[9] Hong K S, Kim J G, Lee K I,"An Integrated Control of Strip Casting Process by Decentralization and Optimal Supervision,"Proceedings of American Control Conference.Philadephia,Pennsylvania,1998,pp.723-727.

[10] QI Chun-yu,DI Hong-shuang ,ZHANG Xiao-ming,GAO De-fu, "Application of Fuzzy Logic Controller to Level Control of Twin-Roll Strip Casting,"Journal of Iron and Steel Research,International,2003,10(4),pp.28-32.

[11] Dussud M,Galichet S,Foulloy L P,"Application of Fuzzy Logic Control for Continuous Casting Mold Level Control,"IEEE Transaction on Control System Technology,1998,6(2),pp.246-256.