Military Technical College
Kobry El-kobbah,
Cairo, Egypt

5th International Conference
on Electrical Engineering
ICEENG 2006

FUZZY LOGIC – BASED CONTROLLER with PI COMPENSATOR in SERVO POSITIONING CONTROL SYSTEM

Said A. Gawish * and A. Kamel**

ABSTRACT

Many types of drives used in positioning systems need high performance controllers to achieve good dynamic performance in the presence of system uncertainty and complex environment. Traditional control schemes like PID can not meet these requirements. On the other hand, a conventional fuzzy logic controller can usually control a nonlinear system more efficiently, and provide better performance than PID controllers in terms of shorter rise time and smaller over shot. Unfortunately, the traditional fuzzy logic controller cannot improve the steady state performance for time varying systems. To overcome this drawback, the integral of the error of the system is taken in consideration. This paper presents a hybrid of the conventional PI compensator with fuzzy logic controller to improve steady–state and dynamic accuracy of the servo position control system. The results obtained indicate that the proposed controller has an excellent position tracking performance compared with both traditional PID controller and fuzzy PD controller.

KEY WORDS

PID controllers - Fuzzy logic controller- PI compensator- Fuzzy PD controller.

INTRODUCTION

Positioning servo system control is a very challenging area in the field of control system engineering, in which different control techniques in linear and nonlinear systems have been developed. The difficulty of position servo systems is caused by its dynamical nonlinearity and complex in environment [1].

---

*Modern Academy for Engineering , Former Head of Electrical Engineering Departments, Military Technical College, Cairo, Egypt .
* Air Defense College, Alexandria, Egypt.

Most types of drives used in the position servo systems require high performance controllers to guarantee good dynamic performance and position accuracy. Different control techniques have been formulated such as conventional controllers, intelligent controllers, and mixture of both with the hybridization of conventional PI control method and fuzzy logic [2,3,4]. In this paper a design methodology of fuzzy logic–based controller with the incorporation of PI compensator has been developed. The block diagram of the positioning servo system equipped with the proposed controller is illustrated in Fig.1. The servo system is composed of a Permanent-magnet brushless dc motor (three phase permanent-magnet synchronous machine) with sinusoidal back electromotive force (EMF) fed from pulse width modulated Voltage Source Inverter (VSI).

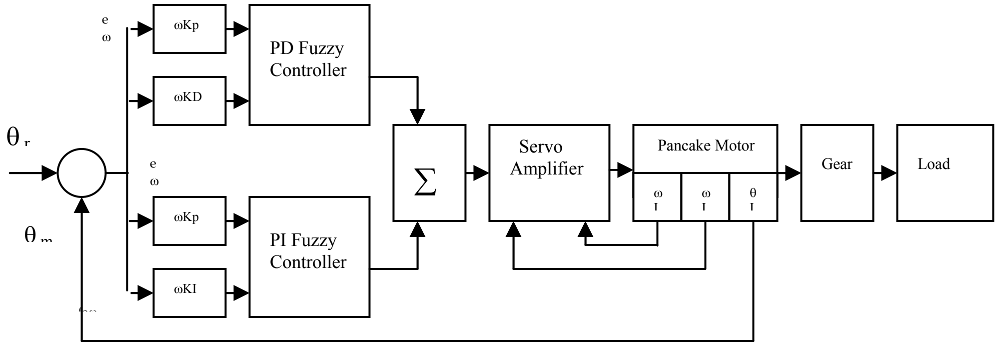


Fig.1 The block diagram of the positioning servo system equipped with PI-Fuzzy controller

The conventional proportional-integral (PI) controllers have great effect in the control of steady state error of a control system, in other words bringing down the steady-state error to zero. However, the disadvantage of this controller is its inability to improve the transient response of the system. With this controller it is very difficult to the system's percentage overshoot and the settling time, which on the other hand, can be controlled by a fuzzy PD controller. This is why many researches use the hybridization of both fuzzy controller and PI compensator [2,5,6].

MODELING OF BRUSHLESS DC SERVO MOTOR

The brushless dc servo motor under consideration is a three phase permanent-magnet synchronous machine with sinusoidal back electromotive force (EMF). The voltage equations for the stator windings can be expressed as [7]:

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ vcs \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} - \begin{bmatrix} L_s & 0 & 0 \\ 0 & L_s & 0 \\ 0 & 0 & L_s \end{bmatrix} d/dt \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} - \omega_r k_e \begin{bmatrix} \sin(\theta_r) \\ \sin(\theta_r - 2\pi/3) \\ \sin(\theta_r + 2\pi/3) \end{bmatrix} \tag{1}$$

where

v_{as}, v_{bs}, v_{cs}	the applied stator voltages;
i_{as}, i_{bs}, i_{cs}	the applied stator currents;
R_s	the resistance of each stator winding;
L_s	the inductance of stator winding;
ω_r	the electrical rotor angular velocity;
θ_r	the electrical rotor angular displacement;
k_e	the emf constant.

The electromagnetic torque can expressed as:

$$T_e = k_t \, [\, i_{as} \sin(\theta_r) + i_{bs} \sin(\theta_r - 2\pi/3) + i_{cs} \sin(\theta_r + 2\pi/3) \,] \qquad (2a)$$

While the torque, speed, and position may be related by:

$$Te = J_m \, (2/P) d\omega_r/dt + B_m (2/P) \omega_r + T_L \qquad (2b)$$

$$\theta_r = \int \omega_r \, dt \qquad (2c)$$

$$\omega_m = \omega_r \, (2/P) \qquad (2d)$$

where

k_t	the current constant;
P	the number of poles;
J_m	the inertia of rotor;
B_m	the damping coefficient;
T_L	the load disturbance;
ω_m	the mechanical angular velocity of the rotor.

FUZZY-PI CONTROLLER

The combination of intelligent control technique and conventional control strategy bring up a new approach in designing an intelligent robust control system. Fuzzy control as one branch of intelligent control, is easy to understand, easy to operate, it has a, quick response and it doesn't need system model [4]. The input of fuzzy controller is the system error and the changing of errors, thus it can be taken as PD controller. Its dynamic characteristics are good and can get stable state smoothly. But its anti-noise is not good and cannot improve the steady state performance. To overcome the disadvantages of both control strategies and to enhance the dynamic system performance fuzzy control and PI compensator have been used at the same time. The two inputs of fuzzy PD controller are the error signal e(t) and the derivative of error ce(t) .

In the proposed positioning servo system the fuzzy input vector comprises the following variables:

$$e(k) = \theta r(k) - \theta m \, (k) \qquad (3)$$

$$ce(k) = e(k) - e(k-1) \qquad (4)$$

where

e(k) is the error at k th sampling interval

ce(k) is the change of error at k^{th} sampling interval
θr (k) is the reference position at k^{th} sampling interval
θm (k) is the motor shaft position at k^{th} sampling interval

The output of the fuzzy controller is the control voltage and is defined as:

$$Uc(k) = Gu^{*}\Delta Uc(k) \qquad (5)$$

Where:
$\Delta Uc(k)$ is the output signal of fuzzy controller at k^{th} sampling interval
Ge, Gce, Gu are the gain factors of the fuzzy controller of fig .1.

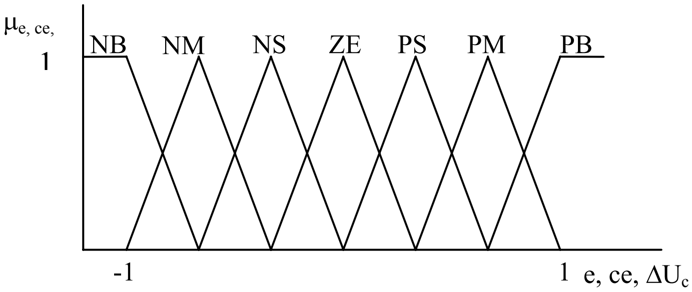


Fig.2 Membership function for e, ce, ΔU_c

The membership classes for the input variables e(k) and ce(k), and the output variable $\Delta Uc(k)$ are shown in Fig.2 The universe of discourse (UOD) for both inputs and outputs is divided into seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero) PS (Positive Small), PM (Positive Medium), PB (Positive Big). The UOD covers a wide range of positive and negative change of the variables e (k), Ce (k) and Uc ((k). The values of e (k), ce (k), and Uc (k) are normalized. Table (1) depicts the output decoding-rule which represents the output control signal $\Delta Uc(k)$ for all combinations of input variables.

Table(1) Rule base for the position controller

e ce	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The rule assignment table is designed using human expertise to generate the output rule when knowing the input rule.

Proceedings of the 5th **ICEENG** Conference, 16-18 May, 2006

SIMULATION RESULTS

With the proposed controller, the motor's angular position should follow arbitrary predetermined reference tracks without overshoot. For verifying the effectiveness of the proposed controller, PID controller and conventional fuzzy PD controller are compared with Fuzzy-PI controller. Also to demonstrate the robustness of the proposed controller the position tracking errors were investigated when the load is disturbed during trajectory control.The PID parameters were adjusted (or" tuned") for meeting the performance criteria Fig.3 shows the performance of the system for step input under exceeding the load by 30%. Fig.4 illustrates the position errors of PID controller, conventional fuzzy PD, and Fuzzy-PI controller. final position errors of the controllers have been presented in table (2), Fig.5, and Fig.6,and Fig.7 present the response of the system when it is disturbed by an impulse at .05 sec. It is clear that Fuzzy-PI controller has much better response than PID and conventional fuzzy PD controller even when the system is disturbed, because the response time is short, no overshot, and it has no steady- state error.

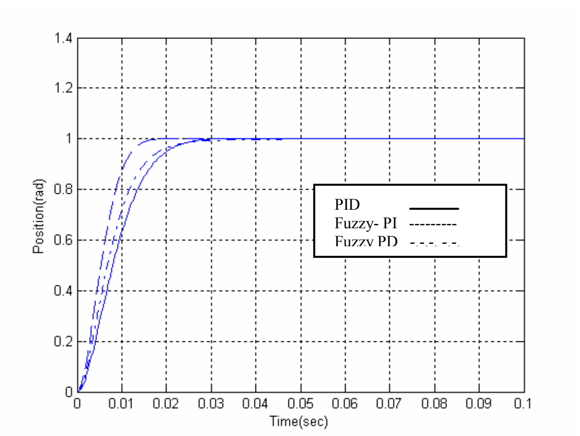


Fig.3 The response of the system
Without variation in system parameters

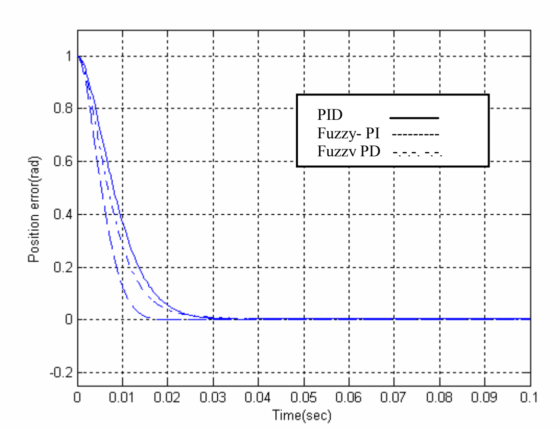


Fig.4 The position errors of controllers

Table (2) the final Position errors

Steady-state error (rad) after disturbance		
PID	Fuzzy PD	Fuzzy-PI
0.003853	0.002047	0.000154

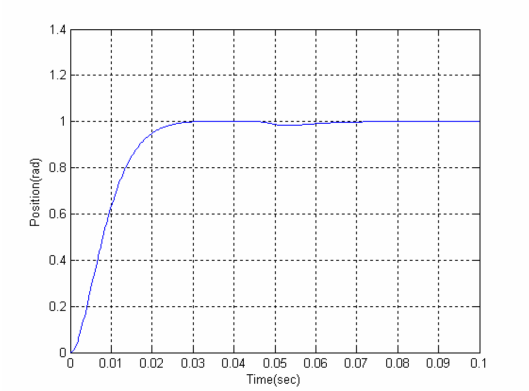


Fig.5 The response of the system with PID controller under disturbance

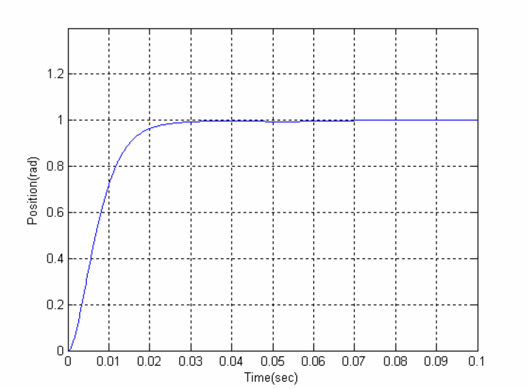


Fig.6The response of the system with fuzzy PD controller under disturbance

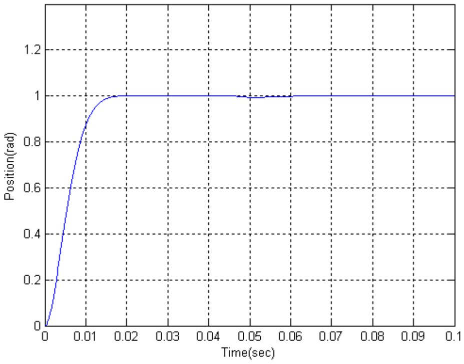
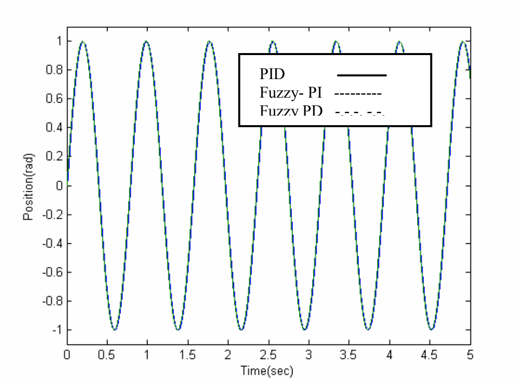


Fig.7 The response of the system with Fuzzy-PI controller under disturbance

Fig.8 indicates the input sinusoidal trajectory, while the investigation of comparing the position tracking errors of controllers when the load is step increased by 30% is illustrated in Fig.9. It is obvious that Fuzzy-PI controller offers the best position tracking error tracking when the load is disturbed



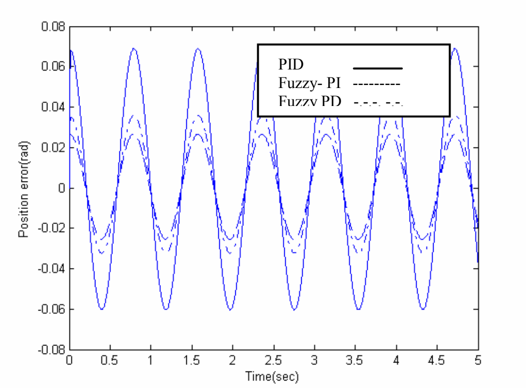


Fig.8 The response of the system with fuzzy PD controller under disturbance

Fig.9 The position tracking error after the load is increased by 30%

CONCOLUSION

The paper developed a combination of fuzzy logic and a proportional – integral controller for enhancing the dynamic performance and controlling the steady-state error of the positioning control system. The simulation results showed that the method of combination of fuzzy logic and proportional-integral controller is not only robust, but also can improve the dynamic performance of the positioning control system it also enhances its anti-error under the variation of system parameters or the load conditions.

REFERENCES

[1] Ohishi K., Ohanshi K., Hotta M.,and Taniguchi M.,"Linear Adaptive Position Control System of Brushless DC Servo Motor," Power Electronics Specialists Conference 1988. PESC'88 Record.,19th Annual IEEE 11-14 April 1988 Page(s):191:198,vol.1.

[2] Y. Zhao and E. G. Cllins, Jr.,"Fuzzy PI Control Design of an Industrial Weigh Belt Feeder," IEEE Trans. Fuzzy Syst. Vol. 11, no. 3, pp. 311-319, Jun.2003.

[3] D. P. Filev and R. R. Yager, "On the Analysis of Fuzzy Logic Controllers," Fuzzy Sets and Syst., vol.. 68, pp. 39-66, 1994.

[4] H. Wang, C. Hu, S. Li, and G. Han," Design and Application of Fuzzy Controller with PI Regulator in Position Control System," Proced. of the 4th World Congress on Intelligent Control and Automation, June 10-14, 2002,page(s): 2537-2540. Shanghhai, R. R. China

[5] Tu Cheng, Fu-Rong Lie, Wen-Li Xu and Yi-Sheng Zhong,"Speed Control of Supersonic Motors by Auto-Tuning Fuzzy PI Control," Proced. of the 4th World Congress on Intelligent Control and Automation, June 10-14, 2002,page(s): 1882-886. Shanghhai, R. R. China.

[6] Ambalal V. Patel,"Simplest Fuzzy PI Controller Under Various Defuzzification Methods," International Journal of computational Cognition,vol.3, no.1, March 2005,page(s):21-34.

[7] Tzuen-Lih Chern, Jerome Chang, and Greeng-Kwei Chang," DSP-Based Integral Variable Structure Model Following Control for Brushless DC Motor Drivers," IEEE Trans. On Power Electronics,vol. 12, no.1,Jan. 1997 page(s):53-63.

14/5/2006