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The Self-Adaptive Fuzzy PID Controller in Actuator Simulated Loading System

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Abstract

This paper analyzes the structure principle of the actuator simulated loading system with variable stiffness, and establishes the simplified model. What's more, it also does a research on the application of the self-adaptive tuning of fuzzy PID (Proportion Integration Differentiation) in actuator simulated loading system with variable stiffness. Because the loading system is connected with the steering system by a spring rod, there must be strong coupling. Besides, there are also the parametric variations accompanying with the variations of the stiffness. Based on compensation from the feed-forward control on the disturbance brought by the motion of steering engine, the system performance can be improved by using fuzzy adaptive adjusting PID control to make up the changes of system parameter caused by the changes of the stiffness. By combining the fuzzy control with traditional PID control, fuzzy adaptive PID control is able to choose the parameters more properly.

Key words: variable stiffness loading, adaptive controller, fuzzy PID

1. Introduction

Steering load simulator is a loading device which is used to provide external resistance on the aircraft in flight simulation when flying [1]. Compared with early mechanical loading system which provides simple linear road, electro-hydraulic loading system supply various ways to load, but electro-hydraulic loading also has many shortcomings [2]. For example, hydraulic source volume, power consumption and large noise, low energy efficiency, oil leakage, malfunction, besides, there is also redundant force because of its structure characteristics, which seriously influence the loading precision and system bandwidth. And now, the popular electric loading system is based on the motor servo system as the actuators which take use of the constant torque output of the Torque Motor to finish the loading task. Compared with the electro-hydraulic system in working band and actuator rang, electric loading system has the following 5 major advantages: 1) the small signal with a stronger tacking ability and higher loading resolution is pretty suitable for work with small load; 2) the system characteristics is stable and influenced little by the environment; 3) the rotary motion of the loading system is suitable for torque loading; 4) the small volume is convenient for maintenance; 5) low noise and environmental friendly [3]. Therefore, the electric loading system is widely used by the researchers in the field.

Both the electro-hydraulic loading system and electric loading system have the problem of redundant force. Redundant force is caused by the motion of the steering engine, and it will influence the precision of the system. What's more, it makes the system frequency width narrow and destroys the stability [4]. Therefore, how to decrease the redundant force is the key to design load simulator and improve the performance of the system, and it is also the difficult point. In this paper, under the control of the servo mechanism, according to the calculation of the Host computer, the system can output corresponding stiffness and load the steering engine with the variable stiffness. In order to further improve the system performance, on the basis of the variable stiffness, the paper introduces the fuzzy adaptive PID control.

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2. Research Method

2.1. Structure Principle of System

The loading system with variable stiffness is consisted of stiffness servo system and torque servo system, and its basic structure can be seen in Figure1.

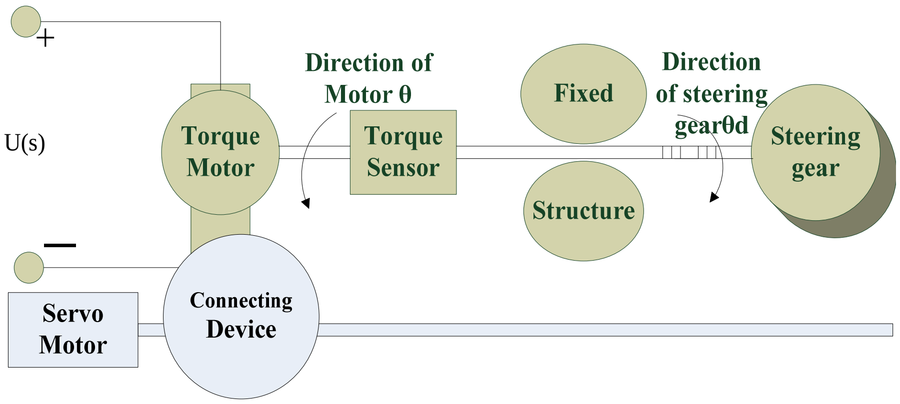

Figure 1. Basic structure of loading system

After receiving the command of position from the processor, AC servo motor runs to the appointed position which is corresponding to the specified value of stiffness of the elastic material. And the stiffness value of the elastic material has been standardized before the system running. According to the instruction of torque, stiffness related and torque sensor signal, the signal generated by the processor controls torque motor, and then, the steering gear is loaded with the help of the coupling shaft. In addition, this system can also be used as a constant stiffness loading system for steering gear. In this paper, the author does some research on the torque servo system and analyzes some characteristics of it.

2.2. The Model of Torque Servo System

The torque servo system consists of torque motor, steering gear and the coupling part between them, both of which are the main factors in building the model of the system. And the simplified model of the system is shown in Figure 1.

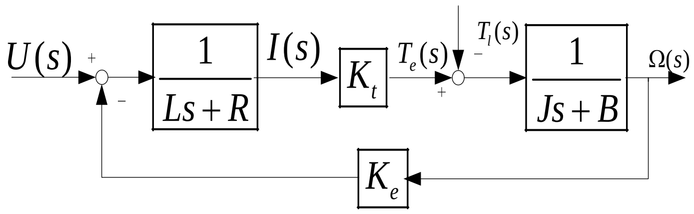

Figure 2. Block of Transfer Function

In Figure 2, you can see the block of torque motor transfer function, thus we can get mathematical model of the motor which is shown below.

$$W(s)=\frac{K_tU(s)-(Ls+R)T(s)}{JLs^2+(JR+BL)s+(BR+K_eK_t)}. \tag{1}$$

Among them, Ω is the speed of motor, U is input voltage of motor, K_t is torque coefficient,

K_e is electromotive force coefficient of counter, L is armature inductance, R is armature resistance, T is output torque of motor, J is moment of inertia, B is damping coefficient.

The balance equation of loading motor and steering torque [5]:

$$T = J\frac{d\Omega}{dt} + K(\theta - \theta_d) \tag{2}$$

Combine Eq.1 and Eq.2, we can know the transfer function of the system:

$$T(s) = \frac{K_t\left(K + Js^2\right)U(s) - K[J_m Ls^2 + \left(J_m R + BL\right)s + (BR + K_e K_t)]sq_d(s)}{\left(J_m + J\right)Ls^3 + \left[\left(J_m + J\right)R + BL\right]s^2 + \left(BR + KL + K_e K_t\right)s + KR} \tag{3}$$

Among them, θ_d is the angular displacement of steering gear, θ is angle of motor, K is the output stiffness of elastic material.

From the equation above, we can see that the part with $\theta_d(s)$ is the disturbance caused by the movement of the steering gear. However, the movement of steering gear can be measured by other device, so we can eliminate this kind of disturbance by using feed-forward control [6]-[9], and the basic principle is shown in Figure 3.

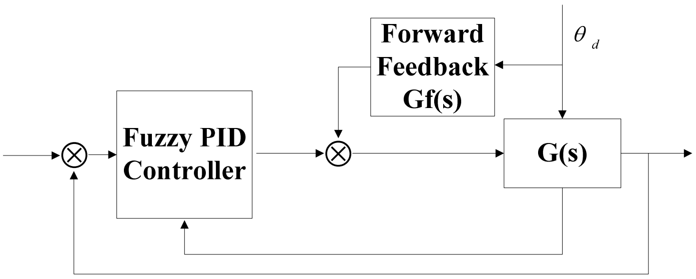

Figure 3. Forward Feedback

Among them, $G_f(s)\theta_d(s)$ can just offset the part with $\theta_d(s)$ in system function, and we can get the final system transfer function shown in Eq.4 below.

$$T(s) = \frac{K_t\left(K + Js^2\right)U(s)}{\left(J_m + J\right)Ls^3 + \left[\left(J_m + J\right)R + BL\right]s^2 + \left(BR + KL + K_e K_t\right)s + KR} \tag{4}$$

2.3. Self-Adaptive Tuning of Fuzzy PID Controller

In self-adaptive fuzzy PID controller, error e and error change ec sever as input factors. According to the rules of fuzzy control, the controller can revise its parameters of PID in time [10] [11]. As a result, it can meet requirements of parameters of PID in different time, thus accomplishing the self-adaptive control. And the structure of the controller is shown in Figure 4.

In this paper, the self-adaptive fuzzy PID controller is applied in the torque servo system, so we should consider the function of the two parameters and the relationship between them in different time. And the self-adaptive fuzzy control is based on the current PID control. By calculating the current system error e and error change ec, and then reasoning with the fuzzy rules, the controller get its proper parameter in the fuzzy matrix built before the running.

According to the practical experience, the parameters including k_p、k_i、k_d , in different cases of e and ec should be adjust to the principle below:

a) When e is a big value, in order to speed up the response of the system and prevent differential overflow caused by the increase of e in the beginning, k_p should be a bigger one while k_d should be a small value. At the same time, because the system overshoot might increase because of the strong action of the integral, we should limit the integral action by taking a smaller value of k_i ;
b) When e is a medium value, in order to reduce the overshoot of the system to guarantee the speed of response, k_p should be reduced properly while the value of k_d and k_i should be moderate ones;
c) When e is a small value, in order to reduce steady-state error, k_p and k_d should be of bigger values. In order to avoid the oscillation of output in the set value and increase the anti-jamming ability, k_i should be a small one when |ec| is in a bigger value.

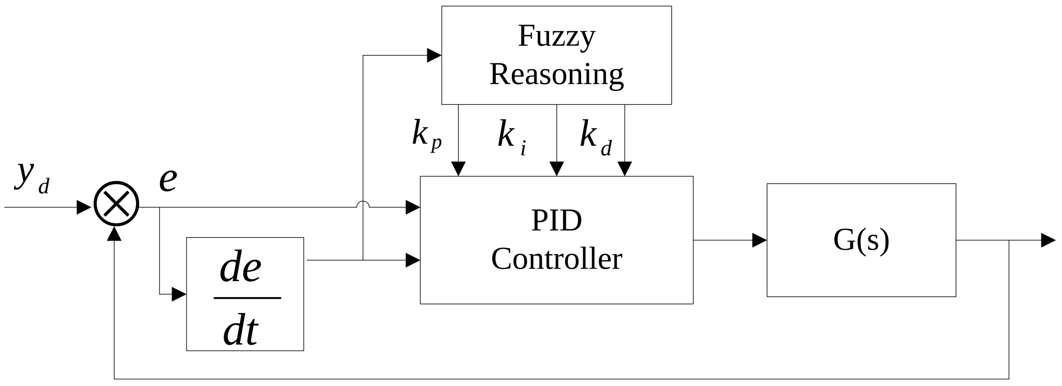

Figure 4. Self-Adaptive Fuzzy PID Controller

The input variable e and ec are divided into seven fuzzy subsets, including Positive Big (PB), Positive Medium (PM), Positive Small (PS), Zero (Z), Negative Small (NS), Negative Medium (NM), Negative Big (NB).

According to the rules above, we can get fuzzy control table below in Table1,2,3.

Table 1. Fuzzy Rules of k_p

Δk_p	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	Z	Z
NM	PB	PB	PM	PS	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	Z	NM	NM	NM	NB	NB

Table 2. Fuzzy Rules of k_i

Δk_i	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NM	NM	NS	Z	Z
NM	NB	NB	NM	NS	NS	Z	Z
NS	NB	NM	NS	NS	Z	PS	PS
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PS	PM	PB
PM	Z	Z	PS	PS	PM	PB	PB
PB	Z	Z	PS	PM	PM	PB	PB

Table 3. Fuzzy Rules of k_d

Δk_d	NB	NM	NS	Z	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	Z
NS	Z	NS	NM	NM	NS	NS	Z
Z	Z	NS	NS	NS	NS	NS	Z
PS	Z	Z	Z	Z	Z	Z	Z
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

According to the fuzzy subset {e, ec}, we can get PID parameters corresponded in the tables. And combine with the function below, we can get the specific PID parameters.

$$\begin{cases} k_p = k_{p0} + \Delta k_p \\ k_i = k_{i0} + \Delta k_i \\ k_d = k_{d0} + \Delta k_d \end{cases}$$

Among them, k_{p0} , k_{i0} , k_{d0} are the initial designed value which can be got with the help of experience. Δk_p 、Δk_i 、Δk_d are PID parameters that you can get from the tables.

3. Results and Analysis

In this paper, the basic parameters in the simulation can be seen in Table 4. And generalization performance standards are all unit matrix.

Table 4. The basic parameters

R/Ω	L/mH	K_e /V/rpm	J/Kgm^2	J_m / Kgm^2	K_t /Nm/A	B/Nm/rpm
6.60	45.3	0.208	4.134*10^{-4}	9.92*10^{-4}	1.72	0

In order to reflect the advantages of self-adaptive fuzzy PID controller, in the simulation, I compare the output of fuzzy PID controller with common PID controller. In addition, I also choose a different input signal, including step signal and sine signal, and different stiffness values in the experiments of simulation.

Experiment 1: with a fixed stiffness value, we explore the output of different controllers while the input signals are all step signals. And the result can be seen in Figure 5.

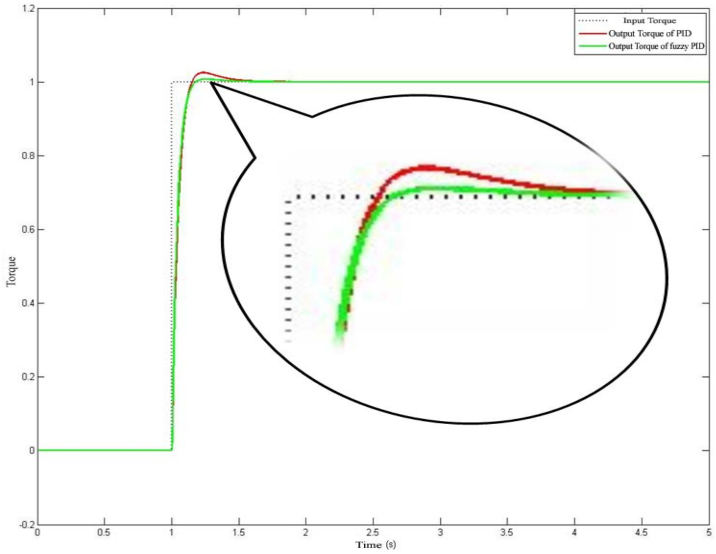

Figure 5. The output of different controllers while the input signals are all step signals

Results of Experiment 1: in Figure 5, we can see that with a fixed stiffness, when the step signal inputs, the overshoot of the fuzzy PID controller has decreased, and the system dynamic performance has been improved.

Experiment 2: in the stiffness value with 2 rad/s frequency variation, we explore the output of the two controllers with the same step signal. And the results of simulation can be seen in Figure 6.

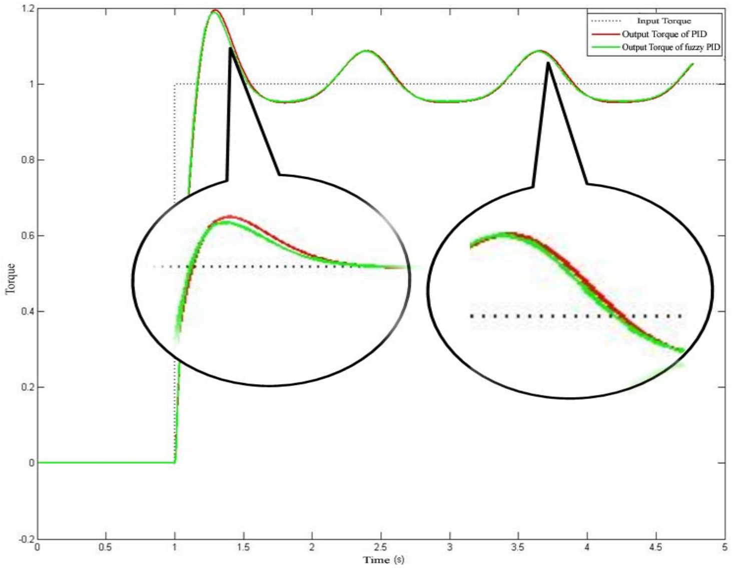

Figure 6. The output of the two controllers with the same step signal

Results of Experiment 2: in Figure 6, we can see that when stiffness changes, fuzzy PID controller can improve the performance of the system, but the improvement is not obvious.

4. Conclusion

This paper studies the self-adaptive fuzzy PID controller in the servo loading system of variable stiffness. As to the characteristics of variable stiffness, the feed-forward control helps to eliminate the system interference caused by the movement of the steering gear. And in the basis of traditional PID, the author designed fuzzy control rules, introducing the self-adaptive fuzzy PID. The results of simulation show that the self-adaptive fuzzy PID controller improves the tracking performance of the loading system, and it can also work in the condition of variable stiffness.

References

[1] Mingli Fu, Gongxia Zhang. Multichannel steering gear motor servo loading device design and realization of the measurement and control system. *Mechanical and Electrical Engineering*. 2009; 38(1) (In Chinese).
[2] Yun;ong Cheng. *Air defense missile autopilot design*. Beijing: Aerospace press; 1993. (In Chinese)
[3] Xiao Pan. Variable stiffness steering load simulation system, Beijing Institute of Technology. 2010, master degree paper. (In Chinese).
[4] Ming Wang. The research of Electric loading simulation. Harbin Industrial University; 2004, doctor degree paper. (In Chinese).
[5] Chenggong Li, Gongtao Jin, Zongxia Jiao. Electric load simulator excess moment generating mechanism and suppression. *Journal of Beijing University of Aeronautics and Astronautics*. 2006, 32(2): 2042208. (In Chinese).
[6] Yunhua Li. Load simulator redundant moment suppression method. *Machine tool and hydraulic*. 1999; (2): 27229. (In Chinese).
[7] Zongxia Jiao, Chenggong Li, Zhiting Ren. The extraneoustorque and compensation control on the electric loading simulator. //The Fifth International Symposium on Instrumentation and control Technology, SPIE. 2003; 5253: 7232727. (In Chinese).
[8] Zhiting Ren, Zongxia Jiao. The design of Small Torque Motor loading Simulator. *Journal of Beijing university of Aeronautics and Astronautics*. 2003; 29(1): 91294. (In Chinese).
[9] Yuan Ci, Keding Zhao. Vehicle load simulation platform velocity feedback overcome excess moment simulation. *Journal of Harbin Industrial University*. 1997; 29(6): 1262129. (In Chinese).
[10] Li Jiejia, Liu Daiyan, Qu Rui. The strategy of construction equipment energy-saving control. *Telkomnika*. 2012; 10(4): 706-712.
[11] LIU Ai-zhen, CHEN Li-yun, WANG Yin-long, Wang Lu. A Quantity Optimization Method on Integrated-Loading-and-Unloading-Missile Vehicles. *Telkomnika*. 2013; 11(2).