FUZZY CONTROLLER DESIGN WITH STABILITY EQUATIONS FOR HYDRAULIC SERVO SYSTEM

Dechrit Maneetham *

Department of Mechatronics Engineering, Rajamangala University of Technology Thanyaburi, Thailand

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ABSTRACT

This paper present a new approach of modeling and simulation of a Hydraulic Servo System (HSS) for a hydraulic mini press machine by using mathematical expressions for describing the spool displacement. The application of a Fuzzy controller to a nonlinear output feedback is investigated, by both the position and the velocity of the hydraulic servo system. The experiment was based on an 8 bit a microcontroller and the simulation was based on a MATLAB Simulink. The simulation and the hardware experimental results have shown that the Fuzzy controller gave the best performance as it had the smallest overshoot, oscillation, and setting time.

KEYWORDS: *Fuzzy control; Microcontroller; Hydraulic servo system; Modeling and simulation*

* Corresponding authors; e-mail: dechrit_m@hotmail.com, Tel.025494755, Fax.025494746

INTRODUCTION

A hydraulic system is widely used in many applications for any field, such as transportation, building construction, factories, together with the performance art and film industries [2]. Since a hydraulic system is a strong actuator system, it has to be substantially controlled in order to achieve the desired purposes and the necessary requirements of safety. In many applications of hydraulic servo systems, when a linear motion is required, a piston control is the first choice[9]. In a simple application that only requires the piston to produce back and forth motions between the two end points, the valve that controls the piston simply operates in an on/off mode [3], [4], [10]. With the development of advanced technology, a combination between a hydraulic servo system and electronic devices was established to take full advantages of the science. At the same time, the most common way is to provide the controller with a way to describe Fuzzy control. The control law design is complex in order to extend to a multi-variable system. In [13], the fuzzy control of a hydraulic servo system gives the fastest response for the characteristics of the system. An optimal tuning of PID is satisfied even in the case where the system is dynamic and the system operating points change [7], [11]. Moreover, a variety of methods have been developed for the modeling and for the simulation such as modeling and the simulation of physical systems and the design an integrated system [5], [6]. In [8], the velocity control of the hydraulic servo system achieves fast response.

The purpose of this paper is to discuss how to achieve the best control performance of a hydraulic press machine. In section 2, the discussion focuses on a dynamic model and on the method used to position the control in hydraulic servo systems. Section 3 presents the conceptual design of a Fuzzy controller. In section 4, simulations and experimental results are separated by comparing the position and the velocity. Finally, the paper is concluded in Section 5.

MODELING OF THE HYDRAULIC SERVO SYSTEM

The system model for a typical inertial load drive by a hydraulic servo system is shown in Figure. 1 and Figure. 2. The hydraulic system was developed by [1]. The system can be thought of as a double acting cylinder driving an inertial load at the end. The dynamic of the inertial load can be written as:

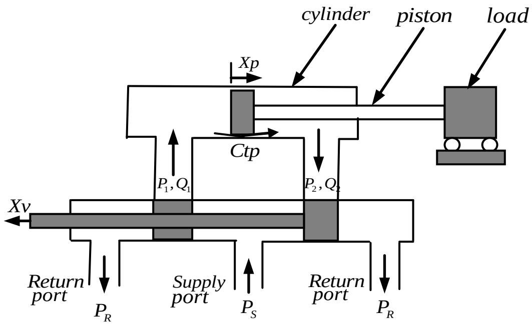

Fig. 1 A hydraulic servo valve

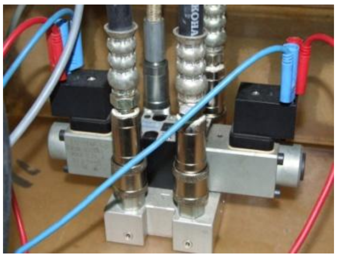

Fig. 2 Photo of high performance hydraulic servo valve

$$\frac{V_t}{4\beta_e}\dot{P}_L = -A\dot{x} - C_{tp}P_L + Q_L \quad (1)$$

$$Q_L = C_d w x_v \sqrt{\frac{P_s - \mathrm{sgn}(x_v)P_L}{\rho}} \quad (2)$$

where V_t is the total actuator volume (m^3), β_e is the effective bulk modulus (N/m^2), P_L is the pressure load (Pa), A is the actuator ram area (m^2), x is the actuator piston position C_{tp} is the total coefficient of leakage $(m^3/s.Pa)$, Q_L is the load flow (m^3/sec), C_d is the discharge coefficient, w is the spool valve area gradient (m), x_v is the spool valve position (m), P_s is the supply pressure (Pa), and ρ is the fluid density (kg/m^3). The valve of friction, a double acting hydraulic cylinder, drives a mass connected to its rod end in a horizontal direction. Thus, the load dynamics, we obtain are:

$$P_L A = mx + kx + F_f \quad (3)$$

where m is the total mass of the actuator, F_f is the friction force, A is the actuator ram area, and P_L is the load pressure, so $P_L = P_1 - P_2$

Assuming Equation (1), (2), and (3), the mathematical model in the system state equations are

$$\begin{aligned} \dot{x} &= x_2 \\ \dot{x}_2 &= \frac{1}{m}(Ax_3 - F_f) \\ \dot{x}_3 &= -\alpha x_2 - \beta x_3 + \left(\sqrt{P_s - \mathrm{sgn}(x_4)x_3}\,x_4\right) \\ \dot{x}_4 &= x_5 \\ \dot{x}_5 &= -\omega_e^2 x_4 - 2\zeta\omega_e x_5 + \omega_e^2 \mu \end{aligned} \quad (4)$$

where $(\dot{x})$ is the actuator piston position, $(\dot{x}_2)$ is the actuator piston velocity, $(\dot{x}_3)$ is the load pressure, $(\dot{x}_4)$ is the valve position, $(\dot{x}_5)$ is the input current to the servo system, $\alpha:\left(4\beta_e A/V_t\right)$, $\beta:\left(4\beta_e C_{tp}/V_t\right)$, and $\gamma:\left(4\beta_e C_d w/V_t\sqrt{1/\rho}\right)$.

FUZZY CONTROLLER

A Fuzzy controller was chosen in for this paper, because of where the two inputs are the position error and its derivative, or the velocity error. To model a system in fuzzy logic, the response of the system, in terms of the input - output, must be known. The designer should be aware of how the inputs and outputs are related. As mentioned, the position and the velocity are the inputs to the fuzzy controller. The logic operations are applied. Seven triangular membership functions are used in the fuzzification 7*7 fuzzy logic rule matrix. The position (ΔP = real time position-set position) and the velocity (ΔV = real time velocity-set velocity) differences are expressed by a number in the interval from -255 to 255 in order to represent distance from -100 to 100 mm/s. According to the rules, the membership function can be given as in Figure. 3 and Figure. 4, while the control surface is depicted in Figure. 5. It can be seen from the surface, which stands for the control voltage, it is impossible to realise this kind of control action for a conventional method.

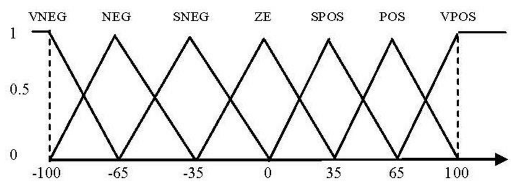

Fig. 3 Membership Function of the Fuzzy controller for Input

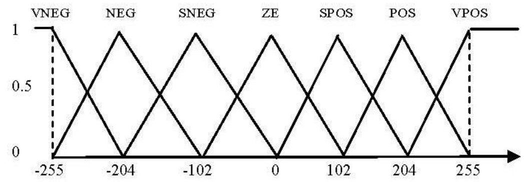

Fig. 4 Membership Function of the Fuzzy controller for output

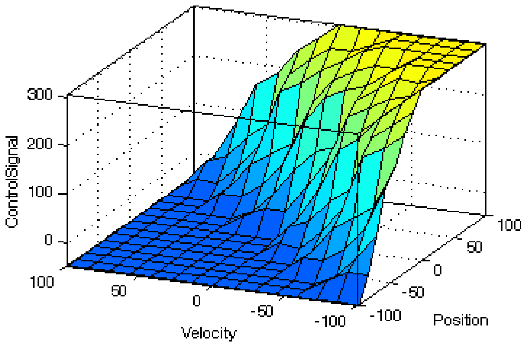

Fig. 5 Control Surface of the Fuzzy controller

Rule1: If ΔP is VNEG and ΔV is VPOS, the ΔO is ZE

[(ΔP = VNEG $\wedge$ ΔV = VPOS); then ΔO = ZE]

Rule2: If ΔP is VNEG and ΔV is POS, the ΔO is SPOS

[(ΔP = VNEG $\wedge$ ΔV = POS); then ΔO = SPOS]

Rule3: If ΔP is VNEG and ΔV is SPOS, the ΔO is POS

[(ΔP = VNEG $\wedge$ ΔV = SPOS); then ΔO = POS]

The input and output regions are related by a set of rules. Once the fuzzy controller is activated, a rule evaluation is performed, and all of the rules which are true, are fired. So with the IF-THEN rule, we can describe the rule of the fuzzy algorithm with the following two dimensional table rules, which are given in Table 1.

The membership function for the two inputs which were the hydraulic position and the velocity. Thus, the membership function of the hydraulic position follows the following equations:

$$VPOS(x) = \begin{cases} (x-65)/35 & when\, 65 \le x \le 100, \\ 0 & otherwise, \end{cases} \tag{5}$$

$$POS(x) = \begin{cases} (100-x)/35 & when\, 65 \le x \le 100, \\ (x-35)/30 & when\, 35 \le x \le 65, \\ 0 & otherwise, \end{cases} \tag{6}$$

$$SPOS(x) = \begin{cases} (65-x)/30 & when\, 35 \le x \le 65, \\ x/35 & when\, 0 \le x \le 35, \\ 0 & otherwise, \end{cases} \tag{7}$$

$$ZE(x) = \begin{cases} (35-x)/35 & when\, 0 \le x \le 35, \\ (x+35)/35 & when -35 \le x \le 0, \\ 0 & otherwise, \end{cases} \tag{8}$$

$$SNEG(x) = \begin{cases} x/35 & when -35 \le x \le 0, \\ (x+65)/30 & when -65 \le x \le -35 \\ 0 & otherwise, \end{cases} \tag{9}$$

$$NEG(x) = \begin{cases} -(35+x)/30 & when -65 \le x \le 35, \\ (x+100)/35 & when -100 \le x \le -65, \\ 0 & otherwise, \end{cases} \tag{10}$$

$$VNEG(x) = \begin{cases} -(65+x)/35 & when -100 \le x \le -65, \\ 0 & otherwise, \end{cases} \tag{11}$$

The membership functions of the hydraulic velocity follow the following equations:

Table 1. The Rules Matrix for a Fuzzy Controller

e/de	VPOS	POS	SPOS	ZE	NSEG	NEG	VNEG
VNEG	ZE	SPOS	POS	VPOS	VPOS	VPOS	VPOS
NEG	SNEG	ZE	SPOS	POS	VPOS	VPOS	VPOS
SNEG	NEG	SNEG	ZE	SPOS	POS	VPOS	VPOS
ZE	VNEG	NEG	SNEG	ZE	SPOS	POS	VPOS
SPOS	VNEG	VNEG	NEG	SNEG	ZE	SPOS	POS
POS	VNEG	VNEG	VNEG	NEG	SNEG	ZE	SPOS
VPOS	VNEG	VNEG	VNEG	VNEG	NEG	SNEG	ZE

$$VPOS(\dot{x})=\begin{cases}(x-65)/35 & when\, 65\le x\le 100,\\ 0 & otherwise,\end{cases} \tag{12}$$

$$POS(\dot{x})=\begin{cases}(100-x)/35 & when\, 65\le x\le 100,\\ (x-35)/30 & when\, 35\le x\le 65,\\ 0 & otherwise,\end{cases} \tag{13}$$

$$SPOS(\dot{x})=\begin{cases}(65-x)/30 & when\, 35\le x\le 65,\\ x/35 & when\, 0\le x\le 35,\\ 0 & otherwise,\end{cases} \tag{14}$$

$$ZE(\dot{x})=\begin{cases}(35-x)/35 & when\, 0\le x\le 35,\\ (x+35)/35 & when-35\le x\le 0,\\ 0 & otherwise,\end{cases} \tag{15}$$

$$SNEG(\dot{x})=\begin{cases}x/35 & when-35\le x\le 0,\\ (x+65)/30 & when-65\le x\le -35\\ 0 & otherwise,\end{cases} \tag{16}$$

$$NEG(\dot{x})=\begin{cases}-(35+x)/30 & when-65\le x\le 35,\\ (x+100)/35 & when-100\le x\le -65,\\ 0 & otherwise,\end{cases} \tag{17}$$

$$VNEG(\dot{x})=\begin{cases}-(65+x)/35 & when-100\le x\le -65,\\ 0 & otherwise,\end{cases} \tag{18}$$

The hydraulic servo system was achieved for the position control of the slider. Thus, the membership functions of the hydraulic output follow the following equations:

$$VPOS=\begin{cases}(x-204)/51 & when\, 204\le x\le 255,\\ 0 & otherwise,\end{cases} \tag{19}$$

$$POS=\begin{cases}(255-x)/51 & when\, 204\le x\le 255,\\ (x-102)/100 & when\, 102\le x\le 204,\\ 0 & otherwise,\end{cases} \tag{20}$$

$$SPOS=\begin{cases}(204-x)/100 & when\, 102\le x\le 204,\\ x/102 & when\, 0\le x\le 102,\\ 0 & otherwise,\end{cases} \tag{21}$$

$$ZE=\begin{cases}(102-x)/102 & when\, 0\le x\le 102,\\ (x+102)/102 & when-102\le x\le 0,\\ 0 & otherwise,\end{cases} \tag{22}$$

$$SNEG=\begin{cases}x/102 & when-102\le x\le 0,\\ (x+204)/100 & when-204\le x\le -102\\ 0 & otherwise,\end{cases} \tag{23}$$

$$NEG=\begin{cases}-(102+x)/100 & when-204\le x\le 102,\\ (x+255)/51 & when-255\le x\le -204,\\ 0 & otherwise,\end{cases} \tag{24}$$

$$VNEG=\begin{cases}-(204+x)/51 & when-255\le x\le -204,\\ 0 & otherwise,\end{cases} \tag{25}$$

SIMULATION AND EXPERIMENT RESULTS

The objective of Simulink was as a hydraulic actuator, which was a representative of a hydraulic servo system. A simulation of the Matlab/Simulink based study was used to evaluate the performances of the controllers on a nonlinear model. The steps for identifying dynamic models of the hydraulic system involve the design an experiment, selecting the model structure, choosing a criterion to fit, and devising a procedure to validate the chosen model.

According to the Figure above, the system is first characterised by the position control (x_1). The piston stroke is $\pm 0.2m.$, the mass of the actuator and the load $m = 9.19Kg.$ The friction relation is approximated as linear $F_f : 0.3063N.$ Secondly, the system was characterised by the velocity control (x_2). Let $\dot{x}_1 = x_2$ be a differentiable function, given by $\int \dot{x}_1 dt = \int x_2 dt$ i. e, we obtain the result in terms of $x_1 = \frac{1}{s}(x_2)$ The response is a set to the velocity and its top most displacement range was Referring the equation $[\dot{x}_2 = \frac{1}{m}(Ax_3 - F_f)]$.

The line block was required for each channel, where the velocity $\dot{x}_2$ was calculated. For that, the area and the force are added in to the block while the friction is subtracted from the block. The third method was to load the pressure system (x_3). This was the most effective method. The pressure of the system was set considering the pressure of the load. The pressure limit was the supply pressure $P_L : 5MPa.$ The value of $\dot{P}_L$ was determined by substituting $\dot{P}_L = x_3$.The models of the components are composed and connected to the blocks. The load flow line parameters are the sum of the blocks from the function $\sqrt{\frac{P_s - \mathrm{sgn}(x_v)P_L}{\rho}}$ after passing through the function C_o block.

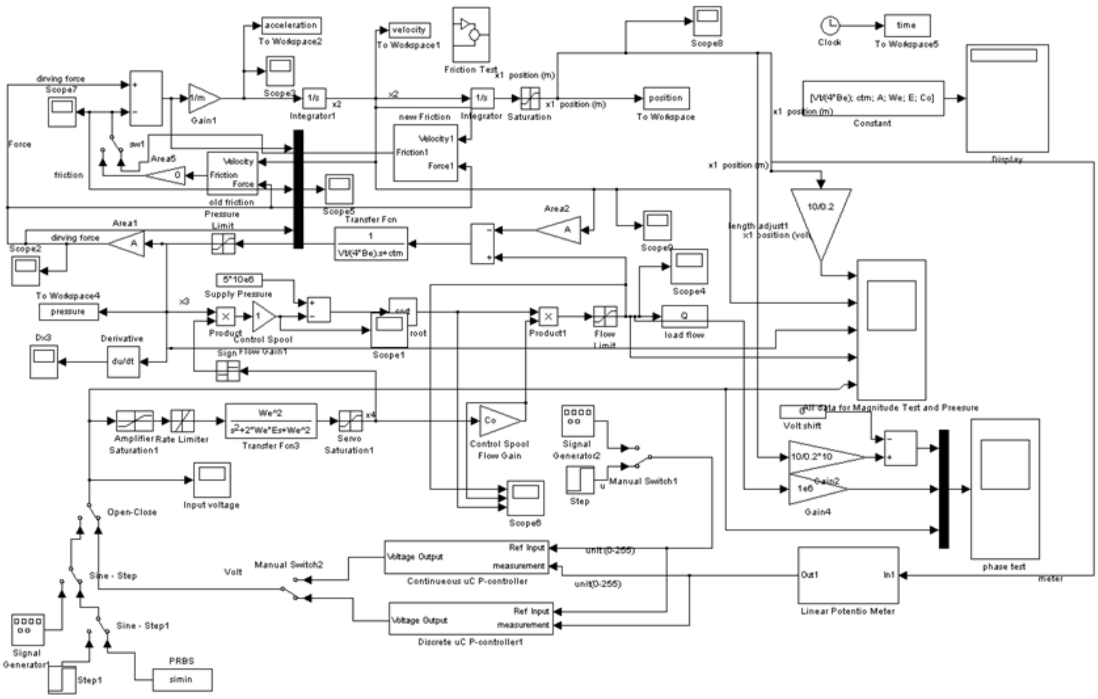

Fig. 6 Matlab Simulink Model of closed loop system

Overall, the main idea of the modified hydraulic subsystems was to use valve position**,** (x_v), the valve velocity $(\dot{x}_v)$ and the input current (u). The upper and lower limits in servo valve were equal to the stroke of the servo valve $x_v : \pm 2.38*10^{-4}m$ and the maximum flow limit through the valve $Q_L : 2.5*10^{-5}m^3/s.$

VALIDATION

The main directions to model the dynamic behaviour of a hydraulic servo system are the various controls of the model's complexity in order to achieve the different simulation and experiments. In the case of the model validation, the controller was modelled using the Simulink approach in the Matlab programme, comparing the position and the velocity of the Fuzzy, which were based on an operating supply pressure of 6 Mpa.

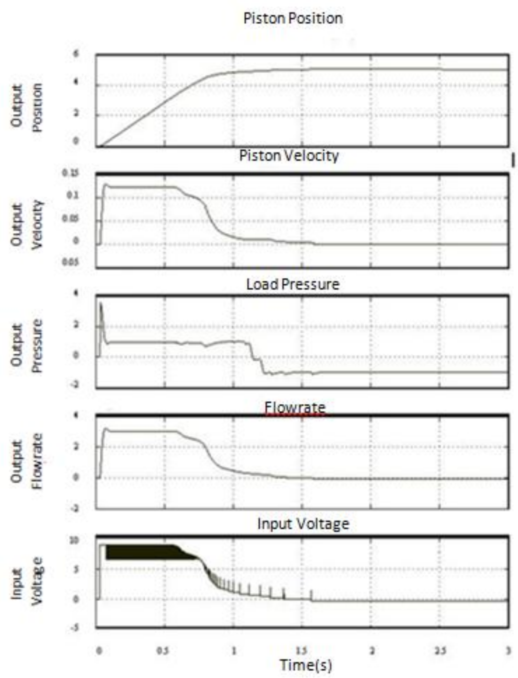

Fig. 7 Observer performances of the step responses with a Fuzzy Controller

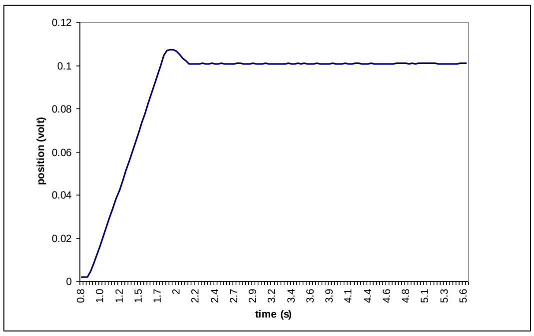

Fig. 8 Unit position responses of the experiment

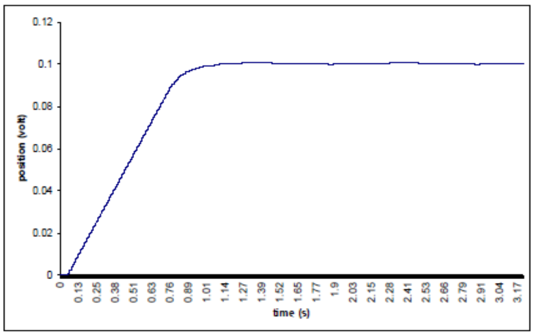

Fig. 9 Unit position responses of the simulation

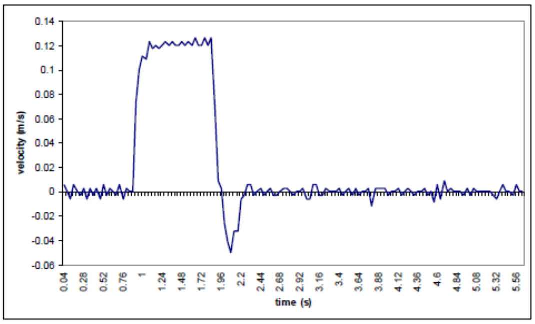

Fig. 10 Unit velocity responses of the experiment

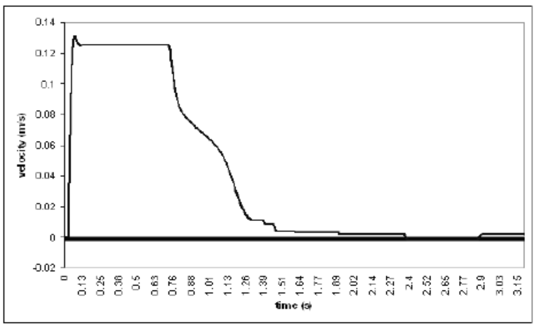

Fig. 11 Unit velocity responses of the simulation

CONCLUSION

This paper has documented the design, experimental evaluation, and the simulation of the position and the velocity servo control of a HSS. The highly nonlinear behaviour of the system has limited the performance of the classical linear controllers that were used for this purpose. It was found that the proposed controller was the Fuzzy both in the simulations and the experiments. The scheme has been tested on various processes in simulations and experiments where an accurate speed control with a fast response time was 0.123 m/s and the position was 42 mm. The simulations and the experiments found a good effectiveness of the Fuzzy method for a hydraulic servo system. The pressure control resulted in a performance error which was lower than any performance error that was controlled when keeping the system stable. Better performances of a higher control precision have been obtained in the position servo control system. This work justifies that the Fuzzy logic has been successfully implemented on the position control of a HSS. The proposed controller offers the Fuzzy method and tracking accuracy of position control in the HSS applications.

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