Velocity Control of Electro Hydraulic Servo System by using a Feedback Error Learning Method

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Abstract

In this paper, a new control method based on FEL electro hydraulic servo control with nonlinear flux and internal friction, has been presented. The new approach based on controllers combined by a classic PD controller and a fuzzy controller is smart. This new technique has a good ability to control the performance and stability. Simulations have been carried out in Matlab environment and the results are presented below.

Keywords: Electro-hydraulic servo system (EHSS), Training feedback error (FEL)

1- Introduction

With the advent of new technologies in recent decades, electro-hydraulic servo system can be noted within a wide range of industrial applications that can be used in industrial control and active suspension system as well as in commercial aircraft, satellites, flight simulators, turbine control and without a number of military applications because of its ability to achieve the high torque and fast response and high accuracy in their performance. [1, 2]. Electro-hydraulic servo control systems have been studied in two classes: 1- position control, 2- speed control or torque. So many control techniques have been introduced in recent decades. The non-linear controller [3] with feedback linearization using the controller in these complex mathematical calculations was introduced more than other control methods [4, 5, 6, 7, 8].

All human movement is done on the basis of the central nervous system as the engine controller is known in the science of neural physiology. Compared with the control engine in the human mind, humanoid robots or other processes that are not under the control of the engine can easily control humans, to do their job. This is due to the violation of their sensors and imprecise and delays inherent in the system or some of the control processes. According to the education system in mind, this phenomenon occurs as well as many of the things that mind control is based on. The idea of early education took place based on error.

The structure [9] was introduced by Japanese scientist Kawato because of errors in the learning process is reversed, and it was named feedback error learning. However, the method is suitable for system control.

This paper is organized in the following form: In Section 2, schematic and non-linear mathematical model of electro-hydraulic servo system is described. In 1-2 general scheme of presentation and display of error-feedback training will be presented. In 2-2, simulation results are presented, and in Section 3, the conclusion is posed.

2-System Description

A schematic representation of an electro hydraulic Velocity servo system is shown in fig 1.
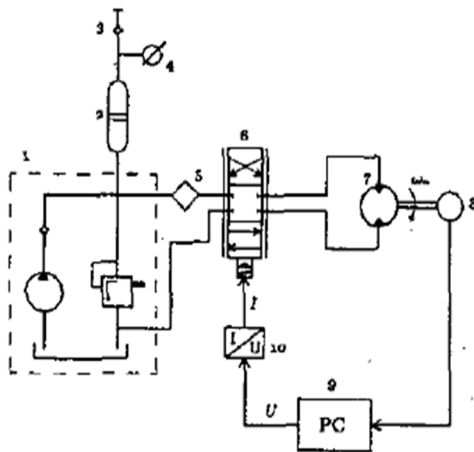

Fig.1.Schematic electro-hydraulic servo system speed dynamics

The basic parts of this system are: 1. Hydraulic power supply, 2. Accumulator, 3. Charge valve, 4. Pressure gauge device, 5. Filter, 6. Tow-stage electro hydraulic servo valve, 7. Hydraulic motor, 8. Measurement device, 9. Personal computer, and 10. Voltage-to-current converter

The states of the system shown in Fig 1 are measured and they are forwarded to the personal computer. Electric voltage signal is generated based on this information according to the designed control law and it is converted to the current by voltage-to-

current converter. This signal acts on the electro hydraulic servo valve which in turn supplies the hydraulic motor with appropriate amounts of oil.

A mathematical representation of the system is derived in using Newton's Second Law for the rotational motion of the motor shaft, the continuity equation for each chamber of the hydraulic motor, and by approximating the connection between the torque motor and the first stage of the electro hydraulic servo valve by a first order transfer function. This representation accounts for flow nonlinearities and internal friction. If the state variables are denoted by:

x_1- Hydro motor angular velocity $\left[\text{rad}/_\text{s}\right]$,

x_2- load pressure differential [pa],

And x_3- valve displacement [m],

Then the model of EHSS in physical coordinates is given by:

$$\dot{x}_1 = \frac{1}{J_t}\{-B_m x_1 + q_m x_2 - q_m C_f P_s \text{sgn} x_1\}$$

$$\dot{X}_2 = \frac{2\beta_e}{V_0}\left\{-q_m x_1 - C_{im} x_2 + C_d W x_3 \sqrt{\frac{1}{\rho}(P_s - x_2 \text{sign} x_3)}\right\} \quad (1)$$

$$\dot{x}_3 = \frac{1}{T_r}\left\{-x_3 + \frac{K_r}{K_q}u\right\}$$

$$y = x_1$$

Where, the nominal values of the parameters appearing in equation (1) are: $J_t = 0.03 \text{kgm}^2$ -total inertia of the

motor and load referred to the motor shaft, $q_m = 7.96 \times 10^{-7} \frac{m^3}{rad}$ - volumetric displacement of the motor , $B_m = 1.1 \times 10^{-3} Nms$ - viscous damping coefficient, $C_f = 0.104$-dimensionless internal friction coefficient , $V_0 = 1.2 \times 10^{-4} m^3$ - average contained volume of each motor chamber , $\beta_e = 1.391 \times 10^9 Pa$ - effective bulk modulus of the system. $C_d = 0.61$ Discharge coefficient , $C_{im} = 1.69 \times 10^{-11} \frac{m^3}{pa.s}$ - internal or cross-port leakage coefficient of the motor, $P_s = 10^7 Pa$ - supply pressure , $p = 850 \frac{kg}{m^3}$ - oil density , $T_r = 0.01s$ - valve time constant, $K_r = 1.4 \times 10^{-4} \frac{m^3}{sv}$ - valve gain, $K_q = 1.66 \frac{m^2}{s}$ - valve flow gain, and $W = 8\pi \times 10^{-3} m$ – surface gradient. The control objective is stabilization of any chosen operating points of system given by x_{1N}- arbitrarily constant value of our choice

$$x_{2N} = \frac{1}{q_m}\{B_m x_{1N} + q_m P_S C_f\}$$
$$x_{3N} = \frac{q_m x_{1N} + C_{im} x_{2N}}{C_d W \sqrt{\frac{1}{p}(P_S - x_{2N})}}$$

While the value of the control signal necessary to keep

x_3 At the equilibrium is $u_N = \frac{K_q}{K_r} x_{3N}$

It is assumed that the motor shaft does not change its direction of rotation, $x_1 > 0$. This is a practical assumption and in order for it to be satisfied, the servovalve displacement x_3 does not have to move in both directions relative to the neutral position $x_3 = 0$. This fact allows us to restrict the entire problem to the region where $x_3 > 0$. In this case, the

mathematical representation of the system is simplified to

$$x_1^{\cdot} = \frac{1}{J_t}\{-B_m x_1 + q_m x_2 - q_m C_f P_s\}$$
$$\dot{x_2} = \frac{2\beta_e}{V_0}\left\{-q_m x_1 - C_{im} x_2\right.$$
$$\left. + C_d W x_3 \sqrt{\frac{1}{p}(P_s - x_2)}\right\}$$
$$\dot{x_3} = \frac{1}{T_r}\left\{-x_3 + \frac{K_r}{K_q}u\right\}$$

$$y = x_1$$

2-1- Design Controller Using Feedback

Before starting the design, using the following variables:

$\forall i = 1,2,3;\ z_i = x_i - x_{iN}$

$v = u - u_N$

Equations of state space equation (1) are rewritten as follows [3]:

$$\dot{z_1} = \frac{1}{J_t}\{-B_m z_1 + q_m z_2\}$$

$$\dot{z_2}$$
$$= \frac{2\beta_e}{V_0}\left\{-q_m z_1 - (C_{im} + \gamma(z_2))z_2 \right. \quad (2)$$
$$\left. + C_d W z_3 \sqrt{\frac{1}{\rho}(P_s - x_{2N} - z_2)}\right\}$$
$$\dot{z_3} = \frac{1}{T_r}\left\{-z_3 + \frac{K_r}{K_q}v\right\}$$
While:

$\gamma(z_2)$

$$:= \frac{C_d W x_{3N}}{\sqrt{\rho(P_S - x_{2N} - z_2)} + \sqrt{\rho(P_S - x_{2N})}}$$
> 0

In this article, we assume $x(0) = 0$ since the variables $x_1 > 0$ and $x_3 > 0$ have been considered, state space variables can be expressed as follows:

$$\{x_1, x_2, x_3\} \in [0, x_{3max}] \times [0, p_s] \times [0, x_{3max}]$$

While

$$x_{1max} = 404 \frac{rad}{s}, p_s = 10^7 pa, x_{3max} = 4 \times 10^{-4} m$$

Considering that the change of variables given and equations state space in the form of equation (2), we have rewritten:

$$\{z_1, z_2, z_3\} \in [-x_{1N}, x_{1max} - x_{1N}] \times [-X_{2n}, p_s - x_{2N}] \times [-x_{3N}, x_{3max} - x_{3N}]$$

Feedback error learning approach was proposed by KAWATO for linear and nonlinear systems [9]. The structure of this method of (2) is shown below:
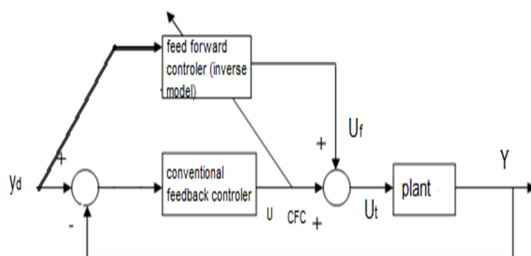

Fig.2. Feedback error learning

Algorithm feedback error learning is composed of two parts:

In the first part, the input signals have been given in the leading path so that the output of the controller can be created.

In the second part, agreement vector control output as error Back propagation of the controller has been leading path.

In Fig.2., System input, output vector control is the way forward and feedback control output vector. Most of the feedback controller or controller in feedback error learning method is used. It is the only criterion for the assessment to obtain feedback controlling interest in the stability of the system.

In Fig.3., schematic representation of control electro-hydraulic servo system has been shown with a fuzzy controller using feedback error learning.
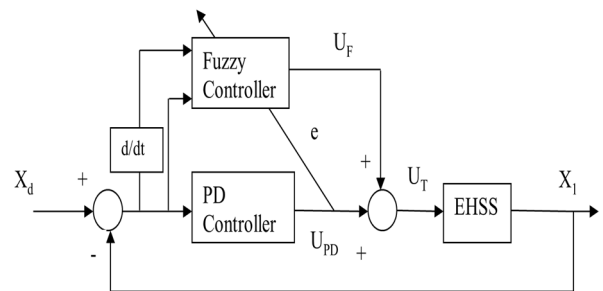

Fig.3. Schematic controller through feedback error learning for electro-hydraulic servo system

Regarding regulation issues, the target point is zero. The input signal is not a good fuzzy controller. Therefore, we have a structure in Fig.3. that has been used in the construction of the road leading controller (fuzzy controller) accepted as input errors.

2-1-1 Feedback Control Contract

Here is a PD controller, which is defined as follows:

$$u_{PD} = K_p(x_{1d} - x_1) + K_d(\dot{x}_{1d} - \dot{x}_1)$$

In which the relative and differential feedback k_d and k_p are owned by PD. Also the controller output contractual feedback is as follows:

$$u_{CFC} = u_{PD}$$

The output of the fuzzy controller is used to update the coefficients of the unknown variables.

2-1-2 Fuzzy Controller

The fuzzy control system for the production of u_f control signal is defined as follows:

$$Rule^{i_1 i_2}: IF\ e_x\ is\ A_1^{i_1}\ and\ e_{\dot{x}}\ is\ A_2^{i_2}\ THEN\ U_F\ is\ \theta^{i_1 i_2}$$

So that

$$A_1^{i_1},\ i_1 = 1,2,...,n_1 \text{ and } A_2^{i_2},\ i_2 = 1,2,...,n_2$$

The membership functions are fuzzy values $\mu_{A_1}^{i_1}(e_x)$ and $\mu_{A_2}^{i_2}(e_{\dot{x}})$ and fuzzy values shown are adjustable and $\theta^{i_1 i_2}$ amounts have been adjusted. D-phase output of the average D centers' fuzzy inference engine has been made. So it can be defined u_f as follows:

$$U_F = \frac{\sum_{i_1}^{n_1}\sum_{i_2}^{n_2}\theta^{i_1 i_2}[\mu_{A_1}^{i_1}(e_x)\mu_{A_2}^{i_2}(e_{\dot{x}})]}{\sum_{i_1}^{n_1}\sum_{i_2}^{n_2}[\mu_{A_1}^{i_1}(e_x)\mu_{A_2}^{i_2}(e_{\dot{x}})]}$$

2-1-3 LEARNING ALGORITHM

The purpose of the training algorithm to update the weights of the network to minimize the cost function is shown by the equation below.

$$E = \frac{1}{2}e^2$$

While:

$$e = u_{CFC} = u_T - u_F \tag{3}$$

Where u_T is final control signal, and u_F is the output of fuzzy controller. The teaching method of propagation parameters using configure the network settings to errors in equation (3) equals zero. Propagation algorithm can be used to weight the equation (4) wrote.

$$\theta(k+1) = \theta(k) - \eta\left(\frac{\partial E(k)}{\partial \theta(k)}\right) \tag{4}$$

So that θ and η represent the adjustable rate and weight training of fuzzy controllers.

2-2 Simulated Results

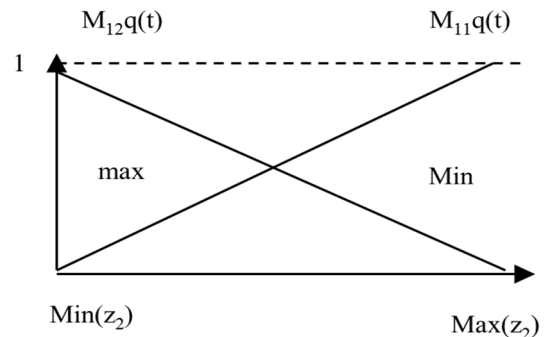By considering the membership in Fig.4.results are shown in fig.5.

Fig. 4. Membership functions

In fig.6. the simulation results by using zero network phases [4] are shown As it can be seen in the proposed meeting time, it takes about 1.4 seconds to go to the meeting of the network and it is less than fuzzy. The meeting time to CMAC and

MLP and RBF methods and feedback linearization method is less. Also it is easier to use controller in this way to design feedback linearization method.
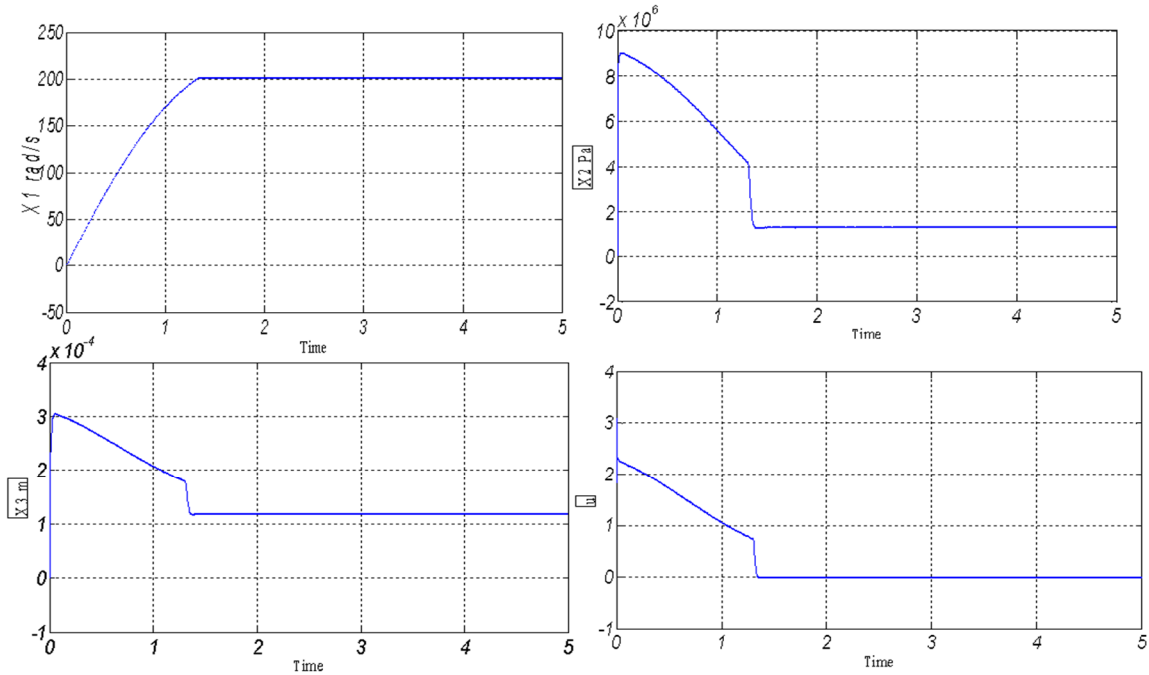

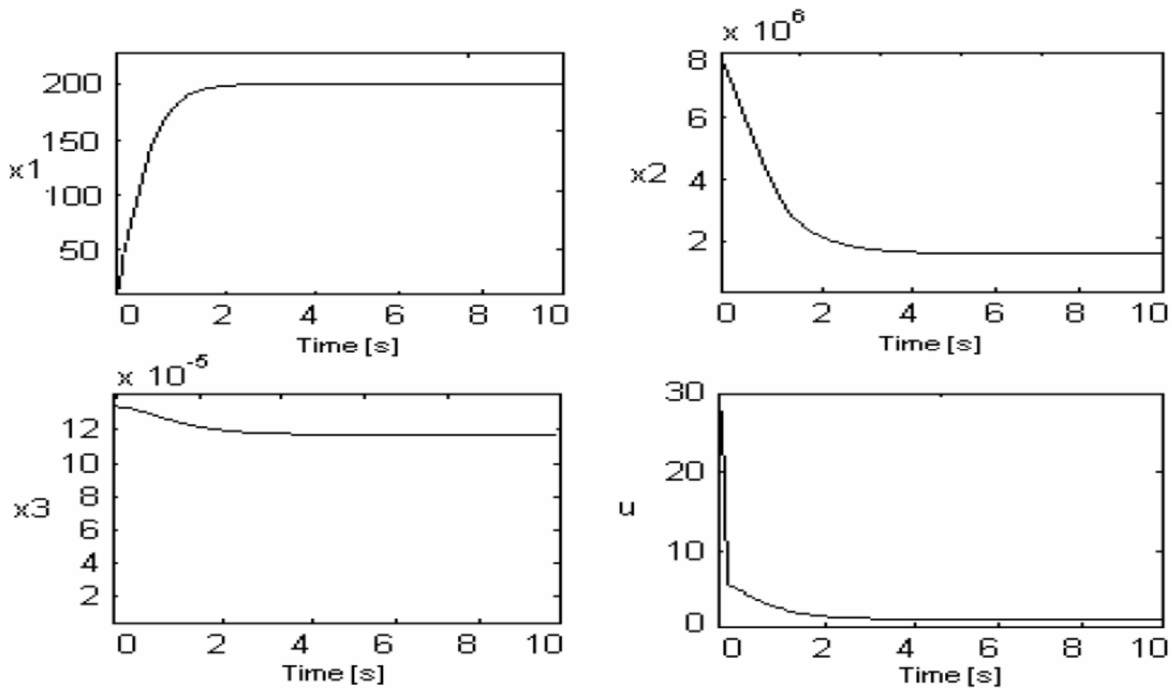**Fig.5** The results of simulated electro-hydraulic servo system using feedback error learning

Fig.6.The simulation results by using FNN method

3- Conclusion

In this article FEL method is provided for controlling the electro-hydraulic servo system which controls the combination of a classical PD controller and a fuzzy controller.

Simulation results show that the proposed controller is less compared to other methods such as settling time FNN that the controller is able to cope with.

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