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Velocity Control of Electro Hydraulic Servo System by Tracking Method

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Abstract

This paper proposes an efficient Tracking method for velocity control of an electro-hydraulic servo system (EHSS) in the presence of flow nonlinearities and internal friction. The tracking method controller is a kind of feedback error learning structure. In the proposed method, the Feedback Error Learning (FEL) algorithm is used to control the velocity. There is no need to compute the system jacobian in FEL method which in turn makes its using more suitable for practical scenarios. This procedure illustrates that EHSS control can be successfully. All derived results are validated by computer simulation of a nonlinear mathematical model of the system.

Keywords: Electro Hydraulic Servo System (EHSS), Feedback Error Learning (FEL), Laguerre Controller

1. Introduction

Nowadays, in most processes, power transmission is conducted at lower costs and with a higher degree of accuracy. For this reason, the application of pressurized fluid in the transmission and control of power systems is growing widely in all the branches of industry. Fluid power is subdivided into Hydraulics and Pneumatics. Pneumatics are used in the cases where relatively low forces (about one ton) and high velocities (such as the systems that are used in the mobile parts of robots) are needed, whereas hydraulics are used in the cases where high power and precisely controlled speeds (such as hydraulic jacks, hydraulic brake and steering) are required.

Hydraulic and pneumatic systems have the following advantages over other mechanical and electrical systems: 1) simple design, 2) the ability to increase the force, 3) simplicity and precise control, 4) flexibility, 5) high efficiency, and 6) reliability. Other advantages include the existence of fewer moving parts, and the ability to achieve, at any point, linear and rotational movements with high power and proper control. Because the transmission of power is done by high-pressure fluid flow in the transmission

In such systems, the controlling task can be performed with little force (such as opening and closing valves). The hydraulic and pneumatic systems can be changed to flexible systems by using flexible hoses in which there are not any spatial constraints in comparison with other systems as they need it for installation. Due to low friction and low costs, hydraulic and pneumatic systems have a high efficiency. Also, the hydraulic and pneumatic systems can be changed to a system which is resistant to sudden loads, excessive heat, and pressure by using safety valves and pressure and temperature switches. Having understood the benefits of pneumatic and hydraulic systems, what follows is a simple explanation of how these systems work.

In recent years more attention has been paid to Electro-Hydraulic Servo Systems by developing of the intelligent control systems. Such systems are characterized by the ability to handle large inertia and torque loads and, at the same time, achieve fast responses and a high degree of both accuracy and performance [1, 2]. The electro-hydraulic servo systems have different industrial applications including active suspension systems, control of industrial robots, and processing of plastics. They are also ubiquitous in commercial aircrafts, satellites, launch vehicles, flight simulators, turbine control, and numerous military applications [3]. The desired control objective species of EHSS are: velocity or force/torque and position control. The details of the control techniques for EHSS are in [4, 5, 6, 7, and 8]. The control technique used to control the velocity of EHSS is feedback error learning which is a very simple This paper is organized in the following way: in section 2, EHSS and its nonlinear mathematical model are described. In section 3, feedback error learning model is introduced for EHSS, Laguerre Controller is introduced in section 4, the simulation results are described in section 5 and section 6 is the concluding part.

2. System Description

A schematic view of the relevant electro-hydraulic servo velocity system is displayed in Fig. 1 The basic parts of this system are: 1) hydraulic power supply, 2) accumulator, 3) charge valve , 4) pressure gauge device, 5) filter, 6) two-stage electro-hydraulic servo valve, 7) hydraulic motor, 8) measurement device, 9) personal computer, and 10) voltage-to-current converter.

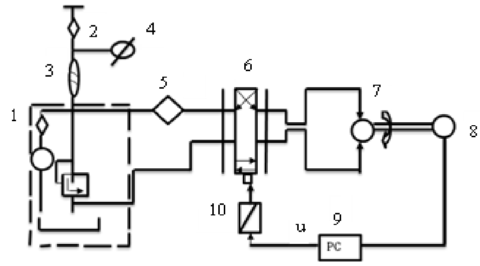

Fig.1. Schematic view of EHSS

Equations of the system using Newton's second law for the rotational motion of the motor shaft are presented as follows:

$$\dot{x}_1 = \frac{1}{j_t}\{-B_m x_1 + q_m x_2 - q_m c_f\, p_s\} \tag{1}$$

$$\dot{x}_2 = \frac{2\beta_e}{V_o}\{-q_m x_1 - c_{im} x_2 - c_d w x_3 \sqrt{\frac{1}{\rho}(p_s - x_2)}\}, \tag{2}$$

$$\dot{x}_3 = \frac{1}{T_r}\{-x_3 + \frac{K_r}{K_q} u\} \tag{3}$$

$$y = x_1$$

Where (x1, x2, x3) are state variables and defined as:

x1: Hydro motor angular velocity
x2: Load pressure differential
x3: Valve displacement

The nominal values of the parameters of the system are presented in Table 1:

Table.1.
The parameters of EHSS and their nominal values

para	Description	Value
j_t	Total inertia of the motor and load referred to the motor shaft	$0.03\,\text{kgm}^2$
q_m	Volumetric displacement of the motor	$7.96\times10^{-7}\ \frac{\text{m}^3}{\text{rad}}$
B_m	Viscous damping coefficient	1.1×10^{-3} Nms
c_f	Dimensionless internal friction coefficient	0.104
V_o	Average contained volume of each motor chamber	$1.2\times10^{-4}\ \text{m}^3$
β_e	Effective bulk modulus	1.391×10^{9} Pa
c_d	Discharge coefficient	0.61
c_{im}	Internal or cross-port leakage coefficient of the motor	$1.69\times10^{-11}\ \frac{\text{m}^3}{\text{P}_\text{a}\times\text{s}}$
P_s	Supply pressure	10^7 Pa
ρ	Oil density	$850\,\frac{\text{K}_\text{g}}{\text{m}^3}$
T_r	Valve time constant	0.01s
K_r	Valve gain	$1.4\times10^{-4}\ \frac{\text{m}^3}{\text{s}\times\text{v}}$
K_q	Valve flow gain	$1.66\,\frac{\text{m}^2}{\text{s}}$
w	Surface gradient	$8\pi\times10^{-3}$ m

3. Proposed Structure to Control The EHSS Velocity

3.1. Feedback error learning

The technique of feedback error learning (FEL) was proposed by Kawato, and its general structure is shown in Fig.2 [8,9].

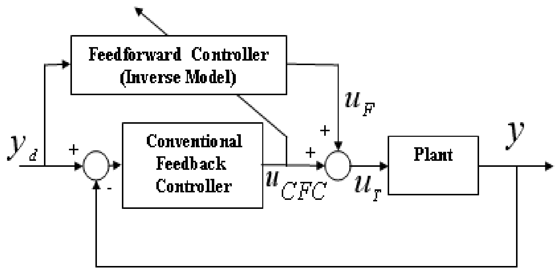

Fig.2. The Feedback Error Learning (FEL) structure

The feedback error learning algorithms consist of two sections: In the first section, input signals are fed in a Feed forward Controller manner through the network to produce actual outputs. In the second section, the output vector of a Conventional Feedback Controller (CFC), U_{CFC} is considered as the error to propagate backward through the Feed forward Controller. The Feed forward Controller does not mimic the Conventional Feedback Controller, but acquires a fully nonlinear inverse model by trying to eliminate the feedback error. In Fig. 2, U_T is the actual input vector to the plant, U_F is the output vector from the Feed forward Controller, and U_{CFC} is the feedback control input vector. In general, the Feedback Controller was realized by a predetermined constant gain Feedback Controller (PID or PD) for FEL scheme in many applications [10].

The only criterion which is important to select the gain is stability of the system [10]. In this article other FEL method (Tracking) is used to control the EHSS. Figure 3 shows this controller structure for velocity control of EHSS.

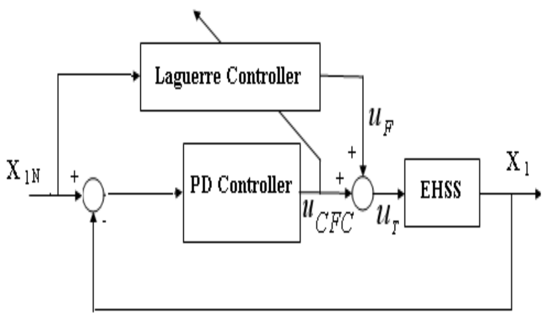

Fig.3. The EHSS velocity control with FEL method

3.2. Conventional Feedback Controller (CFC)

A PD controller was used in conventional feedback controller section and can be represented by:

$$U_{PD} = K_P(x_{1N} - x_1) + K_d(\dot{x}_{1N} - \dot{x}_1) \qquad (6)$$

Where K_P and K_d are proportional and derivational feedback gain.

Choosing proper values for K_P and K_d results in an appropriate PD controller for controlling the velocity of EHSS.

4. Laguerre Controllers

A Laguerre function with length M is constructed of a single pole Low-Pass term at the input and M cascaded All-Pass term after that.

The all-pass terms are also single pole and the positions of all poles in Laguerre structure are the same [11]. A block diagram of continues Laguerre structure is shown in Fig. 4.

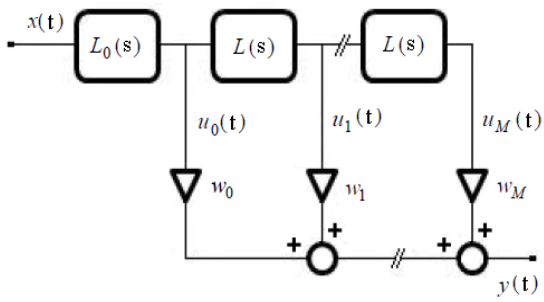

Fig.4. Basic diagram of Laguerre structure

Where $L_0(s)$ and $L(s)$ are described as follows:

$$L_0(s) = \frac{\sqrt{2a}}{s+a} \qquad (7)$$

$$L(s) = \frac{s-a}{s+a} \ , \ a>0 \qquad (8)$$

The output of Laguerre filter is the linear combination of its sections outputs and its weights.

$$y(k) = \sum_{m=0}^{M} w_m \, u_m(k) \qquad (9)$$

With Laguerre structure, the approximation of systems with long or infinite impulse response with smaller number of parameters than transversal structure is possible.

By choosing proper position of the pole of Laguerre structure the appropriate performance and stability of controller is guaranteed.

Laguerre functions can be defined in the Laplace domain as follows:

$$L_K(s,a) = \sqrt{2a}\,\frac{(s-a)^K}{(s+a)^{K+1}} \qquad a>0 \qquad (10)$$

Where k=0, 1, 2 … and a is a positive real number. These functions constitute an orthogonal complete set in the Hilbert space. Rational transfer function of each term of Laguerre structure makes it suitable for practical implementations.

4.1. Training the Weights of Laguerre Structure

In identification applications, it is necessary that the parameters of identifier change over the time to approximate the related system. In Laguerre structure there is two important parameters which can be trained over the time: 1) Laguerre poles and 2) Laguerre weights. There are some adaptive methods to adapt the position of the Laguerre pole in the literature [12]. In this article we place the Laguerre pole in the appropriate position empirically and train the weights of Laguerre structure adaptively. Fig. 5 shows a Laguerre structure which its weights change to minimize the error signal. As we can see the Laguerre output is subtracted from desired signal and the error signal is formed. The Least Mean Square (LMS) algorithm uses this error signal to adjust the weight adaptively. The LMS algorithm is given by:

$$W(k+1) = W(k) + \mu U(k)\, e(k) \qquad (11)$$

Which μ is the learning step size of algorithm.

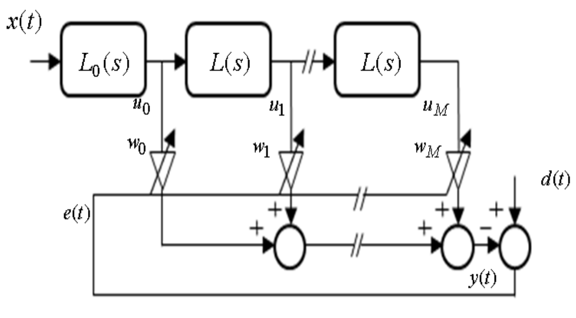

Fig.5.Training the weights of Laguerre structure

With designing a proper Laguerre structure with appropriate length and pole position and training the weights of it adaptively, identifying of unknown systems is possible [13].

5. Simulation

In this article, tracking structure is used to control the EHSS in FEL. Initial conventional feedback controller parameters are:

$$K_p = .0056, K_d = .000057$$

The adaptive Laguerre structure which is used to control the velocity of EHSS has 40 all-pass sections. The pole position of the low-pass section is set to 55 on real axis. The poles of Laguerre all-pass sections are placed on different positions on real axis empirically. This results in better performance than choosing same pole for Laguerre sections. The value of a_i in Laguerre all-pass sections are as follow:

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
10	20	30	40	50	60	70	80	90	100

The learning step size for adaptive learning of Laguerre structure weights is chosen as:

$$\mu = 1\times 10^{-8}$$

Arbitrary constant value and the initial condition of EHSS which described previously are set as follow:

$$x_{1N} = 200\frac{rad}{s} \quad , x(0) = 0$$

Stability of the controller and small settling time are the most important parameters in velocity control of EHSS. In this section the proposed controller was used to show its efficiency in control process. As it can be observed in Fig. 6, the proposed controller is stable and it can control the velocity of EHSS efficiently with settling time 4 s.

In fig 7 is shown a disturbance signal is added to the control signal to evaluate the robustness of controller against disturbance. The disturbance signal is a voltage pulse added to U_T after settling time (I. e., time interval between 6s and 7s). It is supposed that the amplitude of disturbance pulse is 1v and the pulse duration is 1s. Figure 7 depicts the structure of the proposed controller.

The simulation result of the proposed controller in presence of disturbance is shown in fig 8.

The results in fig. 7 and fig. 8 show that the controller can control the EHSS velocity successfully in presence of disturbance and it has an acceptable robustness against disturbance.

6. Conclusion

The control of electro hydraulic system is an important feature in many industrial applications. To properly control the system, many intelligent controllers are presented in recent years. This approach proposes an efficient for velocity control of an Electro-Hydraulic Servo System in the presence of flow nonlinearities and internal friction. The settling time for tracking method is about 4 secs, showing a better response than MLP Neural network, Fuzzy neural network, CMAC controller and nonlinear controller and The control signal controller (u) is better than FNN, RBFSMC, MLP, CMAC and DSMFNN controller. This controller can also control the EHSS in presence of different values of disturbance.

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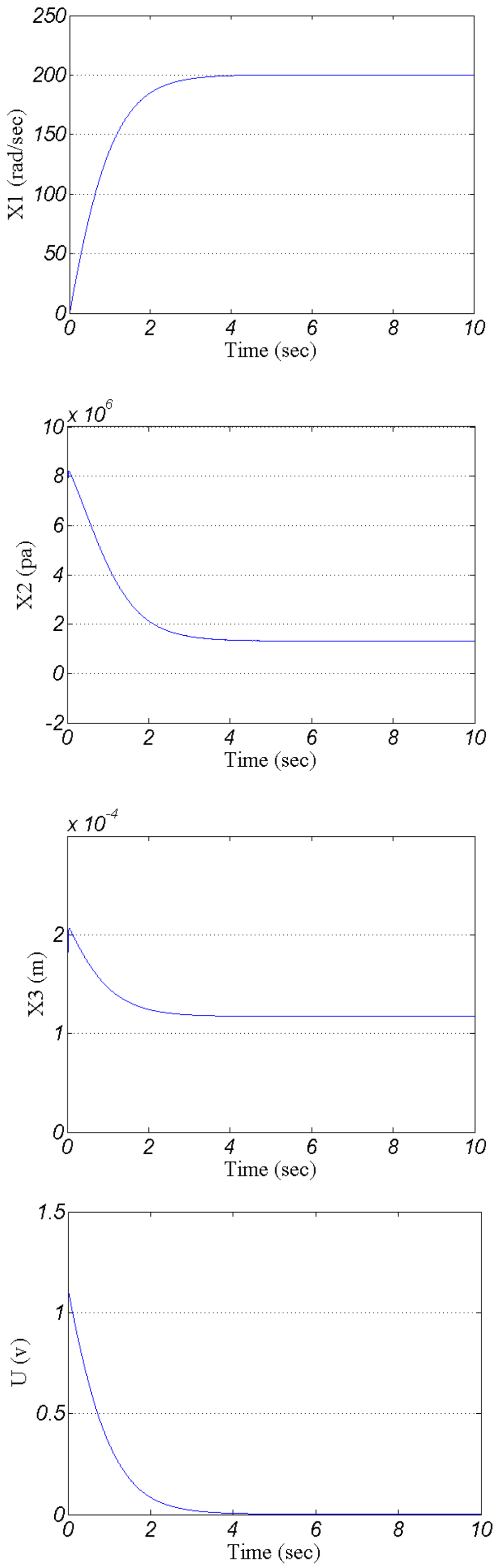

Fig. 6**.** States of system and control signal in velocity control of EHSS by tracking method

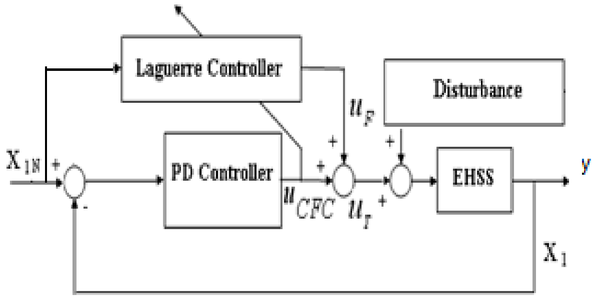

Fig. 7. Structure of controller in presence of Disturbance

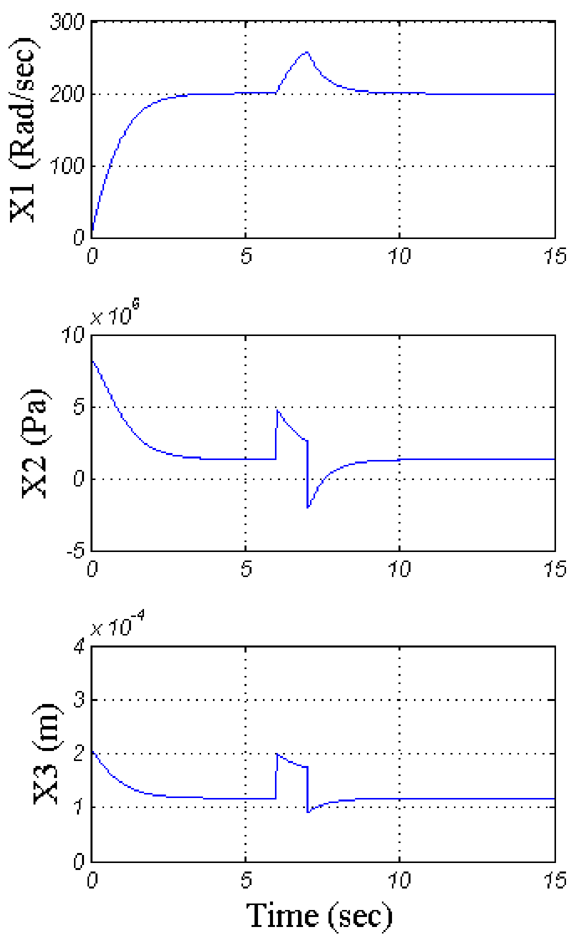

Fig 8. The simulation result of the proposed controller in presence of disturbance

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