ISSN 1454 - 8003
Proceedings of 2017 International Conference on Hydraulics and Pneumatics - HERVEX
November 8-10, Băile Govora, Romania

THE STATE FEEDBACK CONTROL OF WATER HYDRAULIC SERVO MOTOR SYSTEM BY POLE PLACEMENT

Yusuf ALTUN

Duzce University, Engineering Faculty, Computer Engineering, yusufaltun@duzce.edu.tr

Abstract: *The state feedback control is presented by pole placement for the water hydraulic servo motor system in this paper, which is a choice of driving source for many applications. Although the system is highly nonlinear and has uncertainty parameters, it can be linearized around the working points. The pole placement method is used for the velocity control because it has simpler structure and low-cost contrary to advanced controllers or dynamic controllers. In addition, the control enables to place the desired poles. Therefore, the oscillation, settling time and overshoot are regulated to the disturbances thanks to the controller. The simulation results are presented for the control performance.*

Keywords*: hydraulic servo motor, control design, fluid system.*

1. Introduction

Nowadays, water hydraulic servo motor systems, where a hydraulic motor is combined with a servo valve, are a prominent position because of environment-friendly. The system fluid is water because it has prominent features such as clean, non-combustible, cheap, and easily available. Moreover, water hydraulics have a faster reaction according to oil hydraulics. These properties give high opportunity to use for the industry such as food, chemical, forestry. Yet, they have uncertain parameters, highly nonlinearities and disturbances in addition to the leakage flow and friction in valves or actuators, wide friction torque during the lower motor velocity to oil hydraulics, so their applications can be still rather limited. Accordingly, the researchers have studied on the controller design of the systems to improve the motion performance. Many controller designs are performed up to now. In [1], the gain scheduling PID controller is proposed for the wide overshoot and steady-state error. In [2], a sliding mode control together with the disturbance observer is performed for the angle of the system. In [3], some robust control methods including disturbance observer are observed for the system by comparing. In [4], a simple adaptive control is implemented to the system for the control of both angle and speed, which is simple, lower orderly and has fewer adaptive variables. In [5], it is proposed that the PID funnel control together distance approximation aimed to generate the controller signal is proposed for the speed control of the system. In [6], an adaptive output feedback controller design is proposed for the position of hydraulic servo system under uncertain parameters without measuring the states. In [7], a PID control, whose parameters are tuned by genetic algorithm, is designed for the angular motion control of electrohydraulic servo system. In [8], the position control based on the feedback linearization of an electrohydraulic servo system. In [9], a robust adaptive control is implemented for the hydraulic actuators with single-rod. In [10], an adaptive robust controller based on back-stepping technique based is proposed for the electrohydraulic servo systems with uncertain parameters and unknown dead zone. [11], a nonlinear adaptive feedback controller is designed for the position of the system by using Lyapunov approach according to load disturbances and frictions. In [12], an adaptive neural controller is designed for the velocity of the system via feedback linearization. The above studies are either complex or costly for the applications. So, this paper presents that the velocity control of the system via pole placement method for the water hydraulic servo motor systems this paper. Therefore, the success is gained by regulating the system poles against the disturbances.

2. The Water Hydraulic Servo Motor System Model

Figure 1 shows the servo motor system to be controlled. It contains some basic elements. They are a flywheel attached to a servo motor which generates the outputs the rotational $\theta(t)$ angle and spool displacement of $x_v(t)$ servo valve. Therefore, the controller purposes the angle $\theta(t)$ or speed $\dot{\theta}(t)/\omega(t)$ by producing the $u(t)$ control signal in voltage and so it brings about the spool displacing of servo valve.

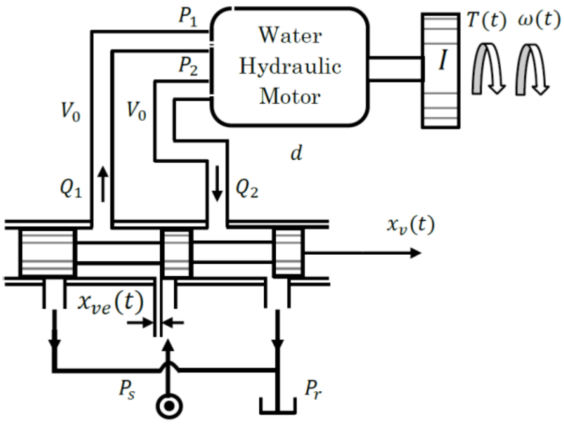

Fig. 1. Water hydraulic servo motor system [4], [5]

The $x_v(t)$ is regarded to u(t) as follows where k_v and τ_v are the gain and time constant of the servo valve dynamics, respectively.

$$\tau_v \dot{x}_v(t) = x_v(t) + k_v u(t) \tag{1}$$

The other nonlinear dynamic equations are detailed in from (2) to (9) in [4]. Where, the of the system is linearized to design the linear controller. Thus, the linearized transfer functions are used in this paper. Accordingly, the friction and leakage flows are omitted and the flow-gain coefficients of the related to servo valves are assumed to equivalent. $k_q = k_{q1} = k_{q2}$. By defining the load pressure (P_L) and the load discharge flow (Q_L), the below equations are obtained.

$$P_L = P_1 - P_2 \tag{2}$$

$$Q_L = \frac{Q_1 + Q_2}{2} = \frac{k_q x_{ve}}{\sqrt{2}} \sqrt{P_s - P_r - sign(x_{ve}) P_L} \tag{3}$$

The Taylor series of (3) are as in (4) where k_x, k_p are determined by test around linearization points.

$$Q_L = k_x x_{ve} - k_p P_L \tag{4}$$

From (8) and (9) in [4], the expression is deducted with neglecting the load flow and all leakages.

$$Q_L = \frac{V_0}{2E} \dot{P}_L + \frac{D_M}{2\pi} \dot{\theta} \tag{5}$$

the dead- zone character and valve dynamics are ignored for the system linearized, and so the x_{ve} spool motion is directly regarded to the $u(t)$ control signal ($x_{ve}(t) = k_v u(t)$). From the other equations in [4], a transfer function from the control input u(t) to the output ω(t) is obtained as in (6) for which the whole leakages and frictions are omitted. State space form can be derived from the transfer function for the controller design.

$$\frac{\omega(t)}{u(t)}=\frac{\left(ED_M k_v k_x/\pi V_0 I_{fw}\right)}{s^2+\left(ED_M^2/2\pi^2 V_0 I_{fw}\right)s+\left(2Ek_p/V_0\right)} \tag{6}$$

Also, the transfer function from the control input *u*(t) to the output *θ*(t) is obtained as in (7).

$$\frac{\theta(t)}{u(t)}=\frac{\left(ED_M k_v k_x/\pi V_0 I_{fw}\right)}{s^3+\left(ED_M^2/2\pi^2 V_0 I_{fw}\right)s^2+\left(2Ek_p/V_0\right)s} \tag{7}$$

3. The Controller Design for with Pole Placement

The pole placement method has been used for the linear control design in the literature. The controller structure is simple for practical implementation. It places the poles of closed loop system. Thus, it can provide stability, disturbance rejection, convergence rate, command tracking, noise dispensation etc. therefore, the controller is designed against the disturbances thanks to the effectiveness by the placing of desired poles.
For the linear system in (8), the controller signal is given by (9), where *r* is the reference signal. The negative sign is used to indicate a negative feedback that is the general status.

$$\begin{aligned}\dot{x}(t)&=Ax(t)+Bu(t)\\ y(t)&=Cx(t)\end{aligned} \tag{8}$$

$$u(t)=-Kx+K_r r \tag{9}$$

So, the closed loop system is obtained as in (10) if the controller signal *u*(t) in(9) is replaced into (8). Accordingly, the closed loop system matrices are in (11). Thus, the matrix *K* provides the stability and K_f provides the reference tracking.

$$\begin{aligned}\dot{x}(t)&=Ax-BKx+BK_r r\\ &=(A-BK)x+BK_r r\end{aligned} \tag{10}$$

$$\begin{aligned}A_{cl}&=(A-BK)\\ B_{cl}&=BK_r\end{aligned} \tag{11}$$

It is tried to appoint the feedback gain *K* in order that the characteristic equation of closed-loop system in (12) is adjusted. This control design via regulating the poles is called as pole assignment or placement.

$$p(s)=s^n+p_1 s^{n-1}+\ldots+p_{n-1}s^{n-1}s+p_n \tag{12}$$

The transfer function from reference signal *r* to output signal y of the closed-loop system is

$$G_{yr}(s)=C(sI-A+BK)^{-1}BK_r \tag{13}$$

So, the static-gain K_r from reference signal *r* to output signal y is equal to (13).

$$K_r=\frac{1}{C(-A+BK)^{-1}B}=\frac{1+LA^{-1}B}{CA^{-1}B} \tag{14}$$

The given K_r is related to the values of parameters. Therefore, the system is calibrated regarding to reference signal. This case is different from a system with integral action, in which the static-gain is not dependent on the values of parameters.

4. Simulation Studies

The whole computations via Matlab™ are performed for the simulation studies. The parameters of the system are as in Table 1 for the simulation studies [5]. The block diagram of control system simulation is as in Figure 2.

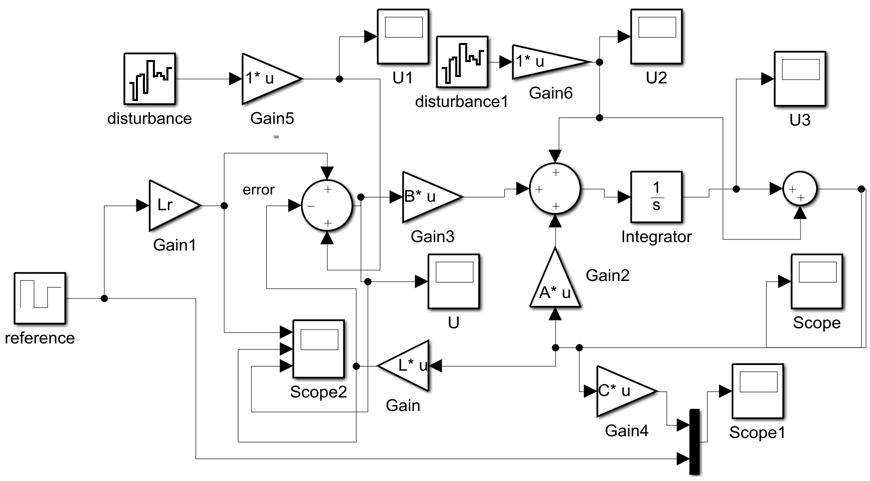

Fig. 2. Simulation block diagram.

Table 1: The values of parameters for the tank system

Parameter	Symbol	Value
Valve time-constant	τ_v	0.02 s
Servo gain	k_v	1.153×10^{-4} m/V
Right valve dead zone	b_r	0.3×10^{-4} m
Left valve dead zone	b_l	0.4×10^{-4} m
Discharge coefficient	C_d	0.61
Bulk modulus	E	2.2×10^{9} Pa
Displacement volume of motor	D_M	15×10^{-6} m^3
Leakage coefficient	C_{Li}	10^{-12} m^3/s Pa
The moment of inertia for flywheel	I_{fw}	4.5 kgm^2
Volume of pipe	V_0	5×10^{-2} m3
Flow gain coefficients	$k_{q1} = k_{q2}$	0.858×10^{-3} $m^2/\sqrt{Pas}$

In accordance with the simulation results, the outputs are as in Figure 3, Figure 4 and Figure 5. According to the references which are stairs type, Figure 3 shows the response of the system output angular velocity without disturbances. The output signal reaches successfully the desired velocity. When is applied the disturbances, which affect the input and output signals, Figure 4 shows the response of the system. Accordingly, the successful of rotational velocity response is decreased in point of reaching the desired reference signal due to oscillation and overshoot. Therefore, the obtained output response is as in Figure 5 when the controller matrices are constructed by changing poles in the design. Thus, the disturbances are attenuated and so the response is improved in point of reaching the desired reference signal. According to results, the system performance is successful despite the disturbances in system.

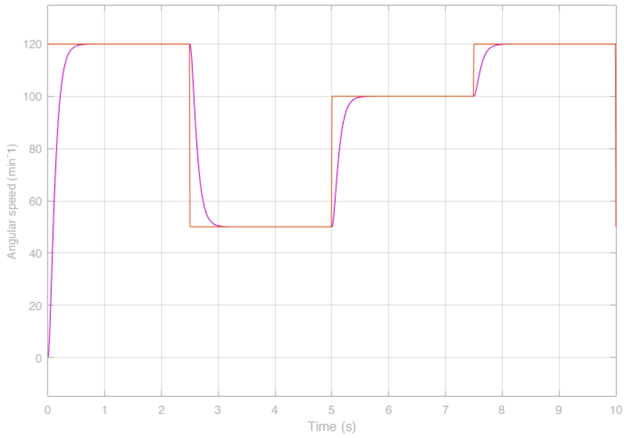

Fig. 3. The angular velocity of the system without disturbances.

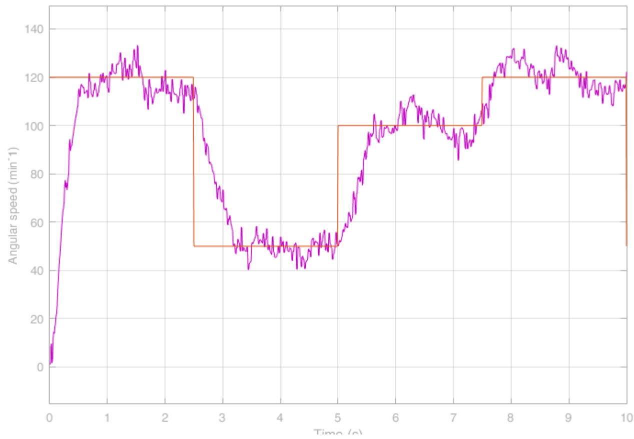

Fig. 4. The angular velocity of the system under disturbances.

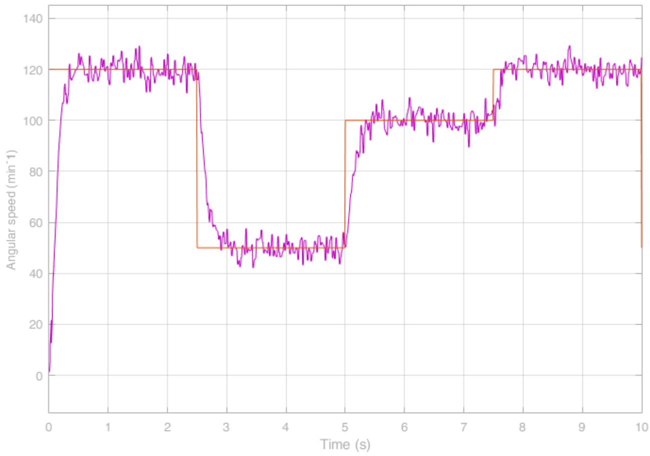

Fig. 5. The angular velocity of the system under disturbances.

5. Conclusions

This paper presents that the state feedback control via pole placement is designed method for water hydraulic servo motor system. The controller is designed by regulating the poles of closed-loop. The design includes the regulation of closed-loop poles against to disturbances for the system. The simulation results show that the controller gives a good performance despite the disturbances which affect input and output of the system. Thus, the simulation results demonstrate that the controller attenuates the disturbances by regulating the poles. Finally, the controller is both simple for the industry and successful against the disturbances.

References

[1] K. Ito and S. Ikeo, "PID control performance of a water hydraulic servomotor system," in *Proceedings of the 41st SICE Annual Conference. SICE 2002.*, 2002, vol. 3, pp. 1732–1735.

[2] K. Ito, H. Takahashi, S. Ikeo, and K. Takahashi, "Robust Control of Water Hydraulic Servo Motor System Using Sliding Mode Control with Disturbance Observer," in *2006 SICE-ICASE International Joint Conference*, 2006, pp. 4659–4662.

[3] K. Ito, H. Takahashı, and S. Ikeo, "Comparative Study of Robust Control for a Water Hydraulic Servo Motor System (2nd report: Disturbance Observer and/or Sliding Mode Control Design Approach)," *Transactions of the Japan Fluid Power System Society*, vol. 38, no. 2, pp. 21–28, 2007.

[4] P. N. Pham, K. Ito, and S. Ikeo, "The application of simple adaptive control for simulated water hydraulic servo motor system," in *Proceedings of the IEEE International Conference on Industrial Technology*, 2013, pp. 204–209.

[5] C. Khajorntraidet and K. Ito, "Water Hydraulic Servo Motor Velocity Control Using PID Funnel Control with Future Distance Estimation," *JFPS International Journal of Fluid Power System*, vol. 10, no. 1, pp. 1–8, 2017.

[6] H.-P. Ren and P.-F. Gong, "Adaptive control of hydraulic position servo system using output feedback," *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, vol. 231, no. 7, pp. 527–540, Aug. 2017.

[7] A. A. Aly, "PID Parameters Optimization Using Genetic Algorithm Technique for Electrohydraulic Servo Control System," *Intelligent Control and Automation*, vol. 2, no. 2, pp. 69–76, 2011.

[8] H. Angue Mintsa, R. Venugopal, J. P. Kenn, and C. Belleau, "Feedback linearization-based position control of an electrohydraulic servo system with supply pressure uncertainty," *IEEE Transactions on Control Systems Technology*, vol. 20, no. 4, pp. 1092–1099, 2012.

[9] B. Yao, F. Bu, J. Reedy, and G. T. C. Chiu, "Adaptive robust motion control of single-rod hydraulic actuators: Theory and experiments," *IEEE/ASME Transactions on Mechatronics*, vol. 5, no. 1, pp. 79–91, 2000.

[10] Y. He, J. Wang, and R. Hao, "Adaptive robust dead-zone compensation control of electro-hydraulic servo systems with load disturbance rejection," *Journal of Systems Science and Complexity*, vol. 28, no. 2, pp. 341–359, 2015.

[11] H. Angue-Mintsa, R. Venugopal, J.-P. Kenné, and C. Belleau, "Adaptive Position Control of an Electrohydraulic Servo System With Load Disturbance Rejection and Friction Compensation," *Journal of Dynamic Systems, Measurement, and Control*, vol. 133, no. 6, p. 64506, Nov. 2011.

[12] Z. Alzahra, S. Dashti, M. Gholami, and M. A. Shoorehdeli, "Neural – Adaptive Control Based on Feedback Linearization for Electro Hydraulic Servo System," *IOSR Journal of Electrical and Electronics Engineering*, vol. 8, no. 1, pp. 2278–1676.