



*Quadratic Regulator (LQR) controller is developed to improve the performance and position tracking performance of EHA system. In order to verify these controllers, it is applied to the real time system and the performance of the system is monitored. The result obtained shows that the output of the system in simulation mode and experimental works is almost similar for both controllers. The output of the system also tracked the input given successfully. Finally, by comparing the best tuning output from these two different controllers, feed forward plus LQR controller proved to give a better output performance than the classical discrete PID controller by minimize the phase lag and reduce disturbance effect in the system.*

**Index terms:** Electro-hydraulic system, System identification, ARX model, PID controller, LQR controller

## I. INTRODUCTION

It is often necessary to design fast and accurate controllers for plants in which system parameters substantially change, or for plants which operate under large external disturbances. To name a few among such plants, there are robot manipulators picking and playing payloads, indexing systems of flexible forging machine which rotate inertia changing work pieces and flight control systems under large wind resistance. In order to satisfactorily control such plants, it is necessary to have an actuator that can supply sufficient instantaneous torque demanded for fast control actions and a control law which enables fast and accurate control under two factors which are internal parameter variations and external disturbances. For an actuator required for control actions, an Electro-hydraulic actuator (EHA) system appears a reasonable choice. Figure 1 shows the actual model of an EHA system.



Figure 1. Model of EHA System



are characterized by nonlinear dynamics, specifically, a square root relationship between the differential pressures that drives the flow of the hydraulic fluid and flow rate.

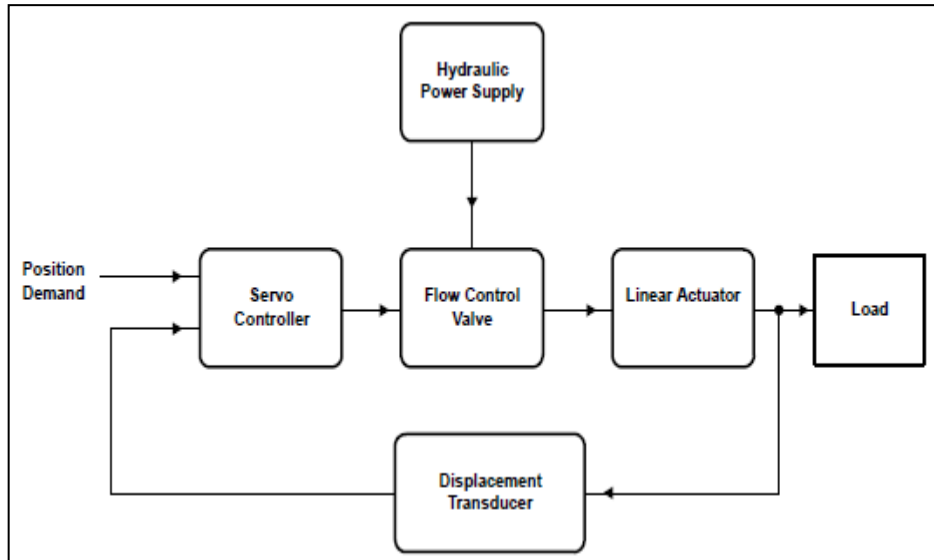


Figure 2: Block Diagram of Typical Positioned Controlled Hydraulic Actuator

b. Previous research on EHA system

A model identification method of electro-hydraulic position servo system based on system identification toolbox in MATLAB and hardware-in-the-loop simulation environment of Real-Time Workshop (RTW) has been proposed[3, 4]. A new nonlinear hybrid controller composed of a proportional controller, a fuzzy controller and a classical PID controller for the model has been introduced. A similar work to identify the model of electro-hydraulic actuator also had been done (Zulfatman and Rahmat, 2009). However, the proposed PID controller for the model can only be applied in simulation mode and limited access to real time implementation.

Regarding to the existing controller design for position tracking control of the EHA system, indirect adaptive controller scheme using pole placement controller was designed in robust mode (Yu, 1996). It was followed by a simple pole placement design and applied to a linearized model of the system (Lim, 1997), and robust controller for a variable displacement hydraulic motor (Plahuta, *et. al.*, 1998). These all aforementioned controllers were designed with the consideration of linear model of the EHA system.

However, the linear controllers contain some limitations to ensure the tracking accuracy and robustness of the controller, especially for highly nonlinear problems. Therefore, nonlinear



$\beta$  = effective bulk modulus

$b$  = viscous damping coefficient

$V$  = total volume of hydraulic oil in the piston chamber and the connecting lines

For zero initial conditions, the Laplace Transform of the equation (1) and (2) produced the following input-output relation,

$$U_p(s) = H(s)X_v + H_L(s)F_L(s) \text{-----}(3)$$

where,

$$H(s) = \frac{4\beta AK_f}{(ms + b)(Vs + 4\beta K_f) - 4bA^2} \text{-----}(4)$$

$$H_L(s) = \frac{-4\beta AK_f - Vs}{(ms + b)(Vs + 4\beta K_f) + 4bA^2} \text{-----}(5)$$

The transfer function of solenoid can be approximated by the servo valve spool position gain denoted by  $k_v$ . Thus, input- output relation (3) can be written as

$$U_p = H(s)k_v V_{in}(s) + H_L(s)F_L(s) \text{-----}(6)$$

where,

$V_{in}(s)$  = Laplace transform of the control voltage  $v_{in}(t)$

Using the equation (1) and (2), linear system with uncertain structure is derived in state space form as,

$$\frac{d}{dt}x(t) = A_o(q)x(t) - B_o(q)v_{in}(t) + D_o F_L(t) \text{-----}(7)$$

$$y(t) = C_o x(t)$$

where,



precision. Thus, ARX model which is the simplest and most popular model is chosen to estimate the EHA system.

#### IV. EXPERIMENTAL SETUP

The experiment setup of the EHA system contains of a few main parts: hydraulic pump, piston, position sensor, servo valve, and hydraulic motor, as shown in Figure 3.

Stimulus signal is generated by a computer, using MATLAB platform, and sent to servo valve through NI-PCI-6221 card. The servo valve is the part to control the flow of hydraulic fluid and move the piston accordingly. The position of piston, which is connected to a load, is captured by wire sensor, WDS 300 p60 attached to the load. The wire sensor is able to measure up to 300mm, corresponding to the piston length, which is 300mm as well. Experiment is start by setting the piston to middle position, to enable it to perform response when stimulus signal is provided.

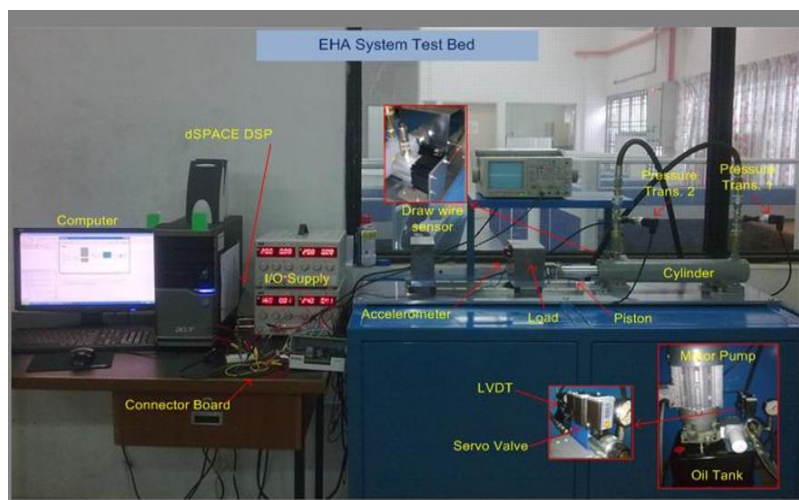


Figure 3: Experimental Setup

#### V. RESULTS AND DISCUSSION

Figure 4 illustrates the complete Simulink block of the system for with PID controller. The input signal excited to the signal will be in the form of step and sine input which will be act as displacement in millimeter (mm).The gain of 1/15 will be given so that the displacement ( $\pm 150$ )





controller's tuning parameters are obtained. The parameters are  $K_p = 6.20968$ ,  $K_i = 3.4198$  and  $K_d = 2.19014$ . The simulation is simulated in discrete form with 0.05second sampling time and the input reference is set to 50mm as the desired position.

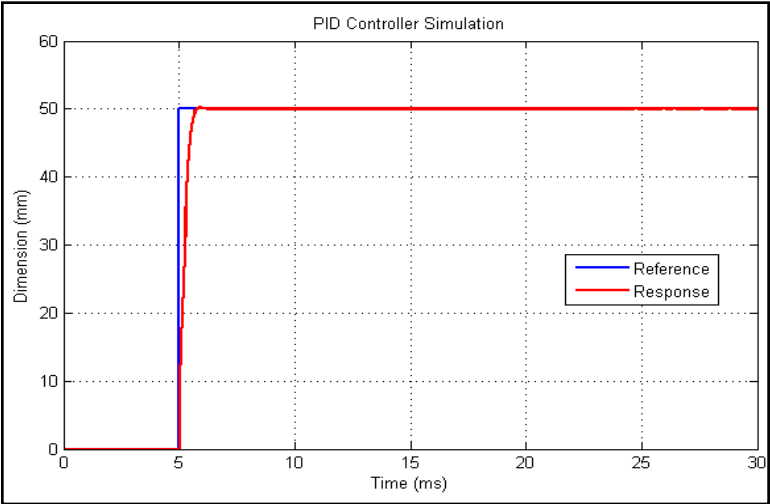


Figure 6: Response of PID Controller with Step Input (Simulation)

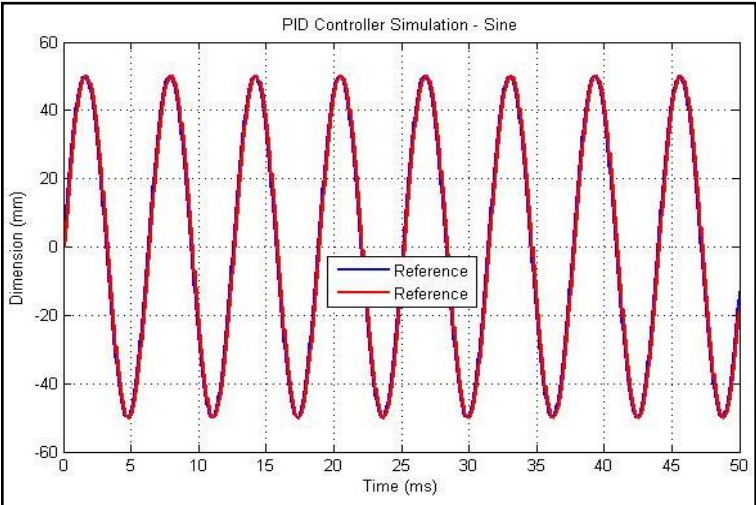


Figure 7: Response of PID Controller with Sine Input (Simulation)

Based on Figures 6 and 7, by adding PID controller in the forward path of the system, the output response of the system with step and sine input are improved. The output of the system has successfully tracked the input given with very small steady state error.



c. LQR plus feed-forward controller via simulation

LQR controller acts as a feedback control which permits the system's output to follow the desired trajectory while feed forward controller is introduced to reduce the phase lag due to feedback control problem. Figure 10 and Figure 11 shows the response of the system with LQR plus feed forward controller with step and sine input respectively. Based on the figures, it clearly shows that the proposed controller achieved good accuracy in 10mm reference trajectory and thus it shows that the linear model is capable to represent the EHA system.

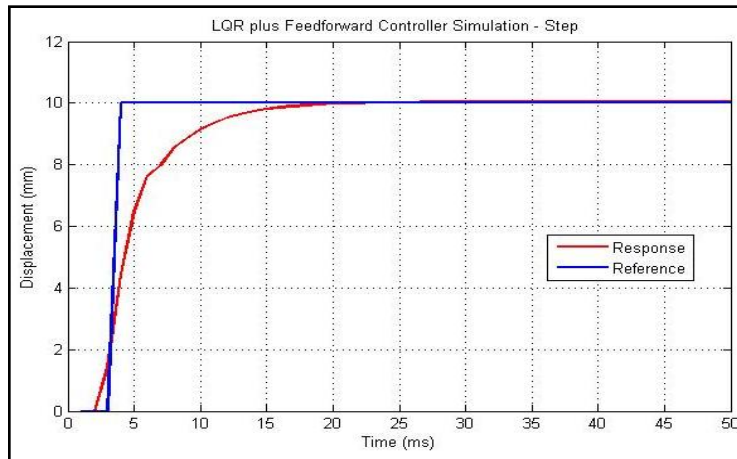


Figure 10: Response of LQR plus Feed Forward Controller with Step Input (Simulation)

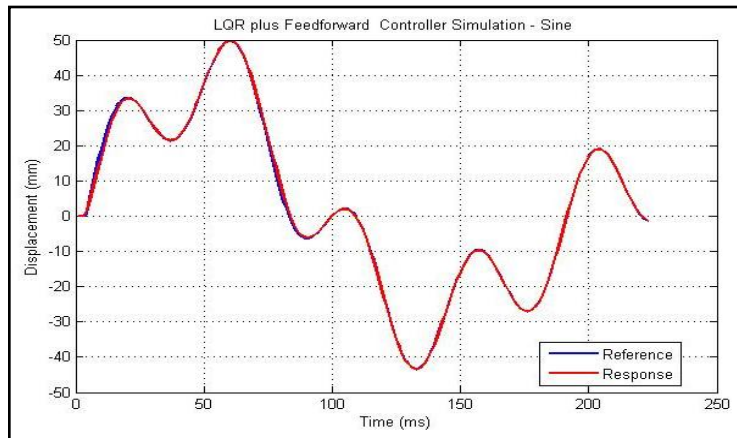


Figure 11: Response of LQR plus Feed Forward Controller with Sine Input (Simulation)

d. LQR plus feed-forward controller via experiment

After obtained the simulation results, the LQR plus feed forward controller is then fed into real plant and the response of the system is observed as shown in Figure 12 and Figure 13. Based on



both controllers output successfully tracked the input given. The LQR plus feed forward controller has better settling time compared to PID controller.

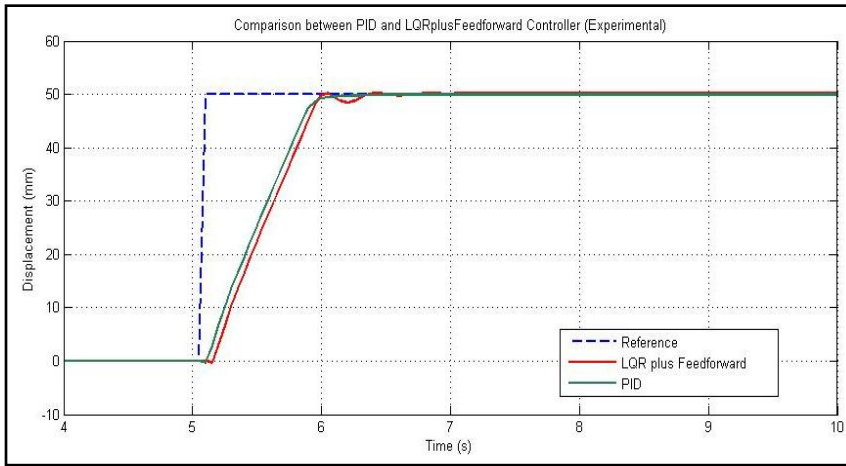


Figure 14: Comparison between PID and LQR plus Feed Forward Controller with Step Input

Significant findings can be shown in Figure 15 which shows the comparison between PID and LQR controller when sine input is given. A random sinusoidal signal is used as a reference trajectory to show the capability in reducing phase error using LQR with feed forward controller. Based on the figure, it clearly shows that the LQR plus feed forward controller tracked down the input given better than PID controller in the form of phase lag. The phase lag is significantly reduced in the LQR plus feed forward controller and thus giving a better performance to the EHA system

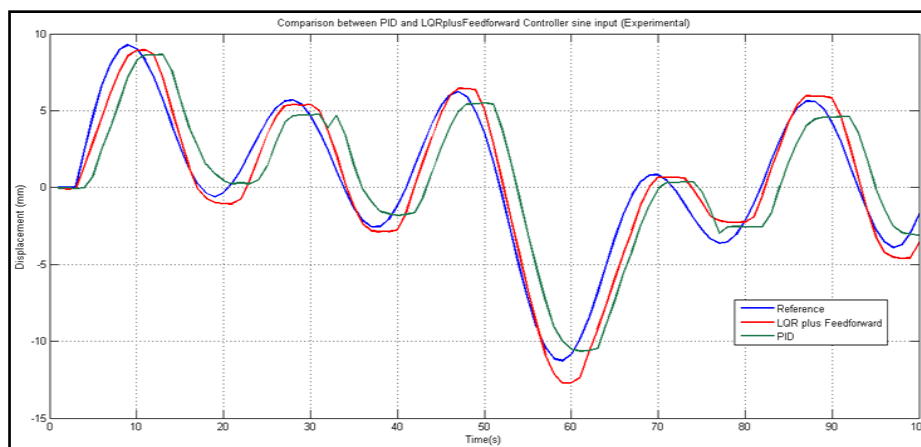


Figure 15: Comparison between PID and LQR plus Feed Forward Controller with Sine Input



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