IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 1 Ver. II (Jan – Feb. 2015), PP 04-09
www.iosrjournals.org

Modeling and simulation of Hydraulic servo system with different type of controllers

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Abstract: *Hydraulic servo systems are characterized by their ability to impart large forces at high speeds and are used in many industrial motion systems. The goal of this paper is to present a mathematical model of a complete hydraulic servo system (solenoid valve, hydraulic valve, actuator, and controller). The model is developed for the system and simulation is carried out with four types of controller namely Proportional (P) control, Proportional-Differential (PD) control, Proportional-Integral (PI) control and PID control. The results of simulation with different controller are discussed and compared.*
Keywords: *Hydraulic, Servo, Mathematical model, Simulation, PID, Controller.*

I. Introduction

Hydraulic servo systems are used where high power and/or high dynamic response is required. Hydraulic servo systems have wide range of applications in machine tool, material handling, mobile equipment, plastics industry, steel plants, mining, oil exploration and automotive testing. The main advantages of Hydraulic servo systems are greater precision, faster operation and simpler adjustment. They can maintain high loading capabilities (high pressures, flow rate) for longer period of time. The response of the hydraulic system depends on the type of the controller used. Hence it becomes important to know the output characteristics of the hydraulic servo system in order to select the proper type of controller for various application. An attempt has been made in this paper to simulate the hydraulic servo system with different type of controller and to compare the results of the simulation.

II. System Description

The block diagram of hydraulic servo system is shown in below figure. This feedback signal is compared with the input signal. The controller uses the resulting error to supply the necessary signal to the servo valve. The servo valve controls the fluid flow to the actuator in proportion to the drive current from the servo valve. The actuator then forces the load to move. Thus, a change in the command signal generates an error signal, which causes the load to move in an attempt to zero the error signal.

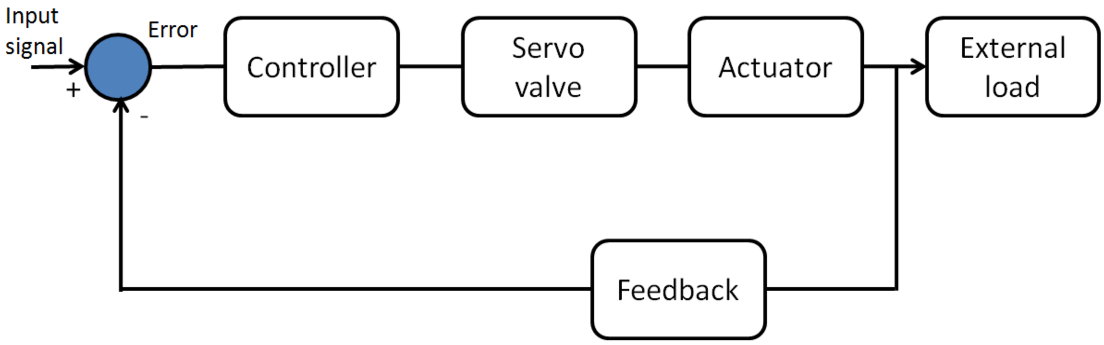


Fig. 1. Block diagram of hydraulic system

III. Modeling Of The System

1. Assumptions

1) The body is considered rigid. 2) Leakage of fluid is neglected. 3) Frictional force is ignored.

2. Solenoid valve model

Solenoid, which receives electrical signals, plays an important role to accomplish flexible and accurate actuation. The voltage applied to the solenoid coil results in the current flowing through the coil. The plunger will move under the influence of magnetic field induced by the current. The current is function of resistance and

inductance of coil. Inductance in turn depends on spool position of the valve. At equilibrium point, plunger becomes stationary.
In order to represent servo valve dynamics through a wider frequency range, transfer function is used as approximation of the valve dynamics. The relation between the servo valve spool position xv and the input voltage u can be considered as a second order system.

$$T(s)=\frac{x_v(s)}{u(s)}=\frac{\omega_e^2}{s^2+2\zeta\omega_e s+\omega_e^2}$$

3. Hydraulic valve model

As plunger moves, spool coupled with plunger is also displaced. The spool displacement opens the orifice at a rate decided by the controller. Pressure starts building up through the orifice, in the cylinder. Consequently flow force acts on the spool which tries to oppose the motion of spool.

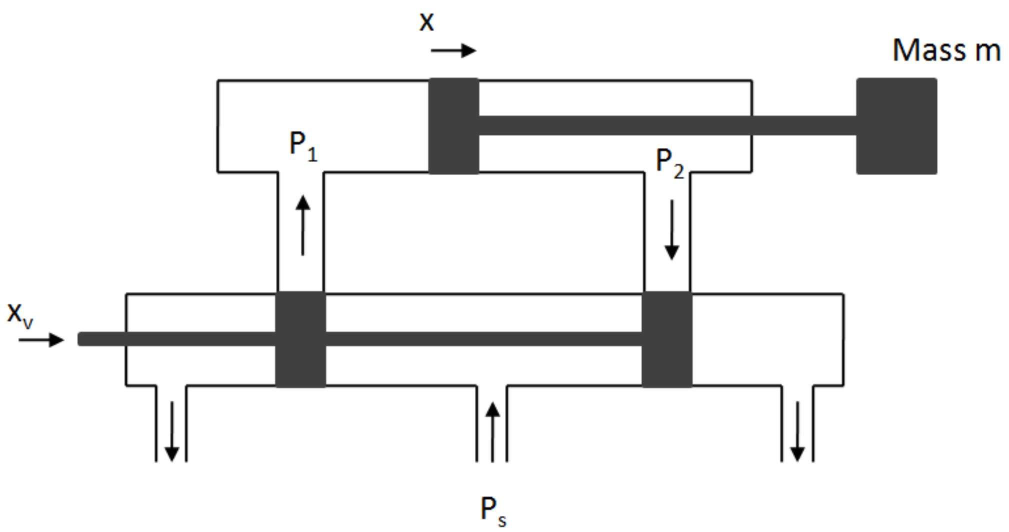


Fig. 2. Schematic of the hydraulic system

The spool movement generates the orifice which causes the flow of fluid in the chambers of cylinders. Defining the load pressure PL as PL = P1 - P2 and the load flow QL as QL = (Q1+Q2)/2, the relationship between the load pressure PL and the load flow QL for an ideal critical servo valve with a matched and symmetric orifice can be expressed as follows.

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

Where Cd is coefficient of discharge, w is valve spool area gradient, Ps is supply pressure and ρ is hydraulic fluid density.

4. Actuator model

Hydraulic cylinder with non-equal piston chambers is considered. The figure shows the schematic of the hydraulic system. The spool in the valve controls the fluid flow in the hydraulic cylinder. As a result the piston moves and applies load on the test component. Pressure in the chamber grows and pressure difference is created in cylinder. The pressure differential of fluid at piston of cylinder drives the load. The mathematical model is represented by the following equation.

$$\dot{P}_L = \frac{4\beta}{V_t}(Q_L - A\dot{x})$$

Where Vt is actuator volume and β is bulk modulus.

The piston force equation is given by:

$$P_L A = m\ddot{x} + kx$$

5. Controller model

Based on the input from the error signal the servo controller, according to a pre-defined control law generate a command signal to drive the solenoid position. Simulation is carried out with four types of controller namely Proportional (P) control, Proportional-Differential (PD) control, Proportional-Integral (PI) control and PID control. The equation of PID form of control is shown below which contains all the type of above controller.

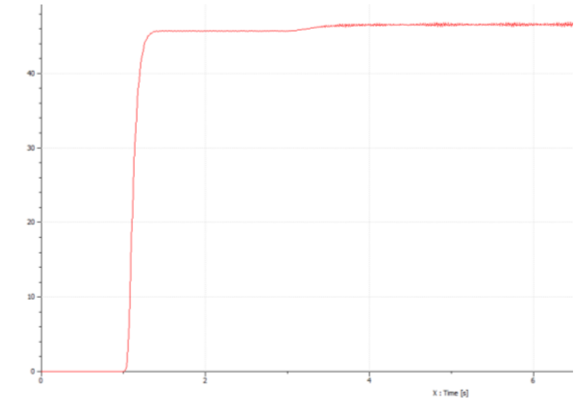
$$u_v(t) = K_p u_e(t) + K_i \int u_e dt + K_d \frac{du_e}{dt}$$

where Kp, Ki, and Kd are the PID constants, ue is the error signal and uv is the controller output.

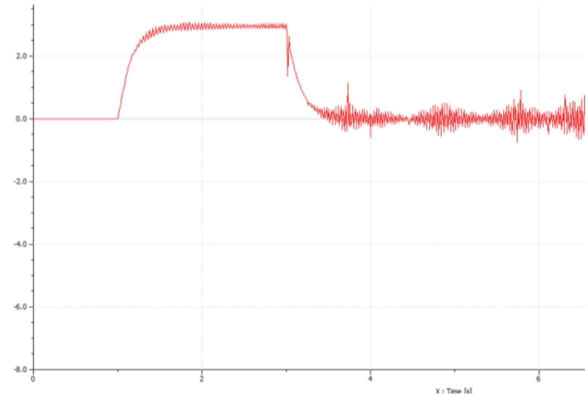
IV. Simulation Results

Mathematical model of hydraulic servo system is simulated for Proportional (P) control, Proportional-Differential (PD) control, Proportional-Integral (PI) control and PID control. The important responses like Cylinder pressure, cylinder flow rate, piston displacement and spool velocity are plotted to get the characteristic of the output.

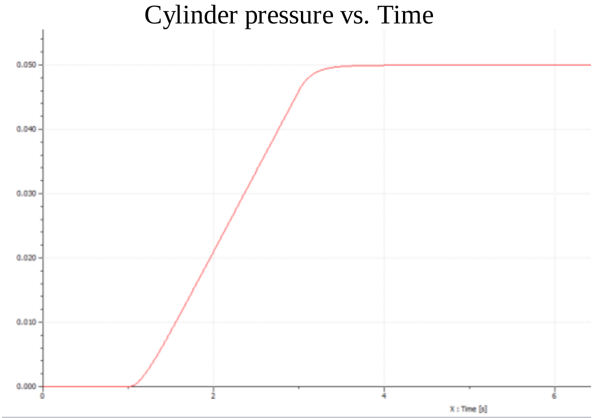
1. P control



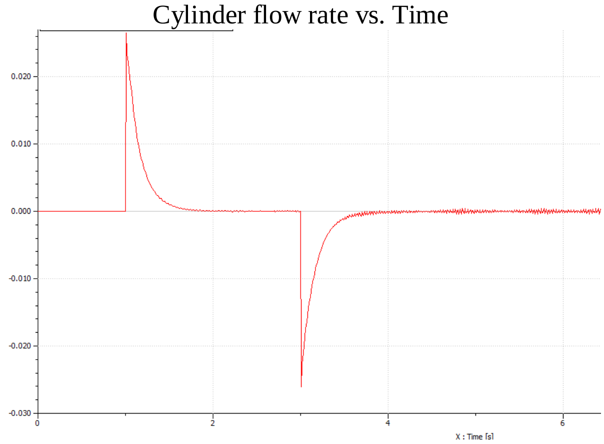
Cylinder pressure vs. Time



Cylinder flow rate vs. Time



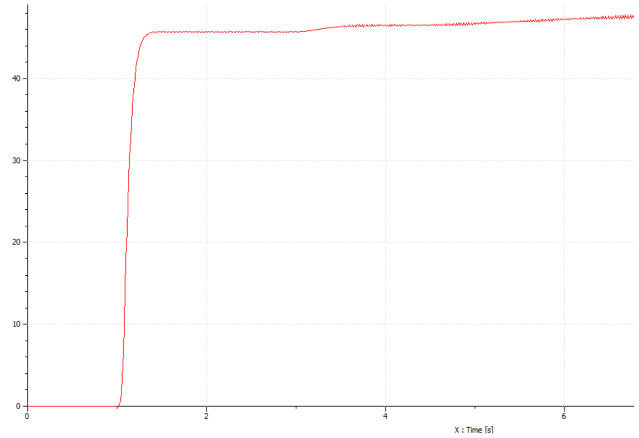
Piston displacement vs. Time



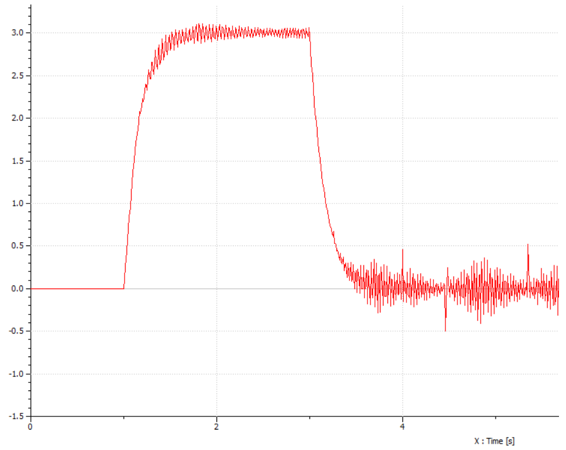
Spool velocity vs. Time

Fig. 3. Simulation results with P type controller

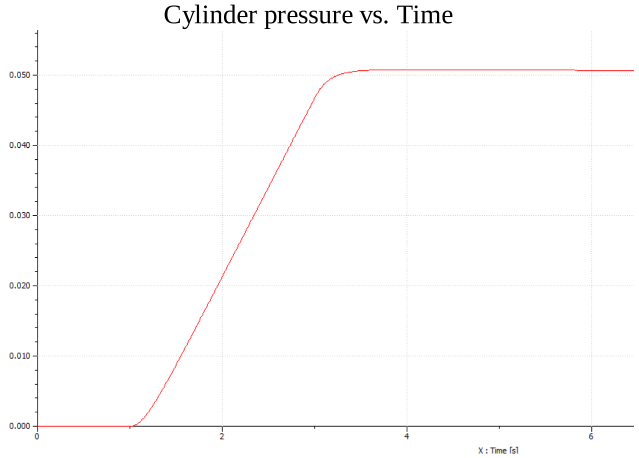
2. PI control



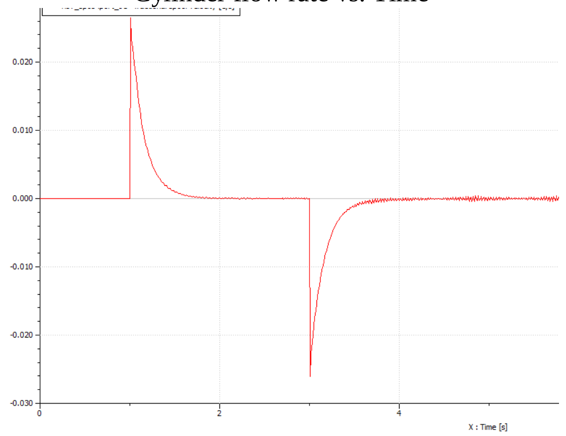
Cylinder pressure vs. Time



Cylinder flow rate vs. Time



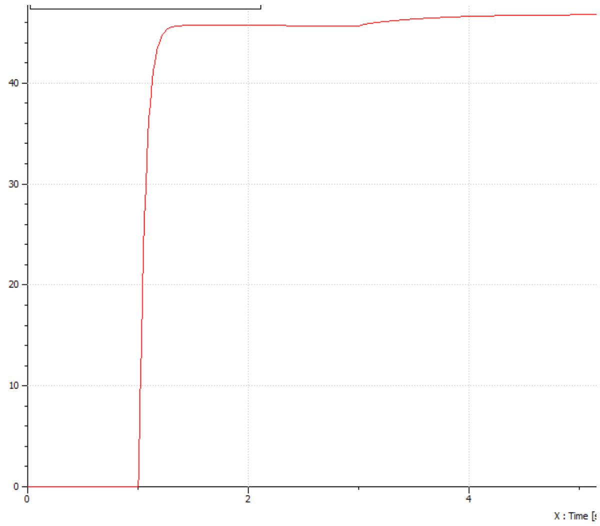
Piston displacement vs. Time



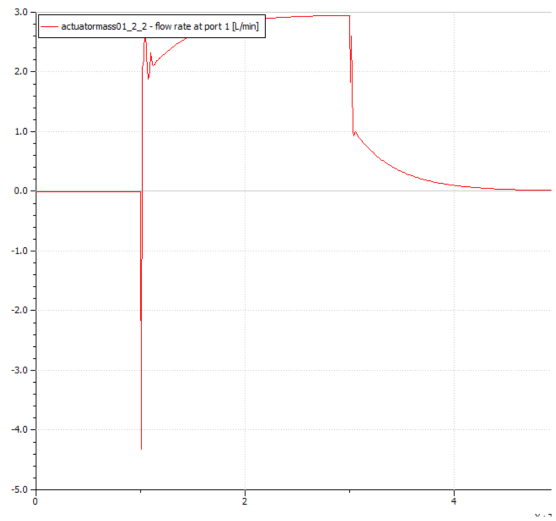
Spool velocity vs. Time

Fig. 4. Simulation results with PI type controller

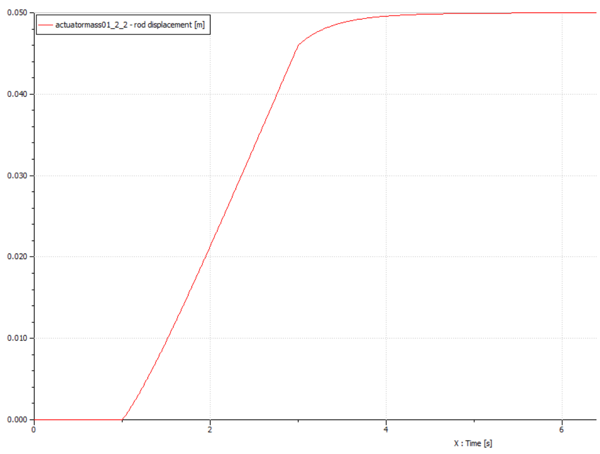
3. PD control



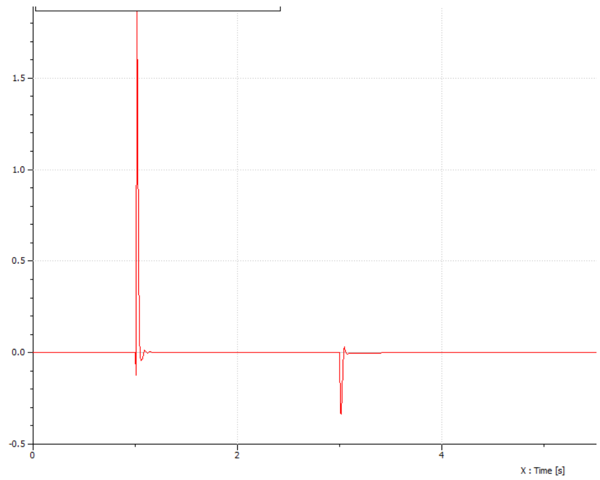
Cylinder pressure vs. Time



Cylinder flow rate vs. Time



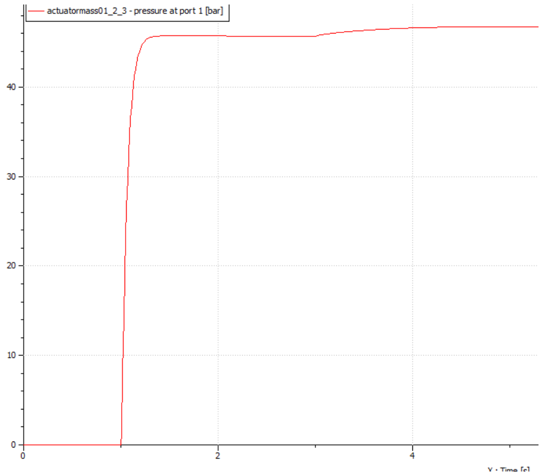
Piston displacement vs. Time



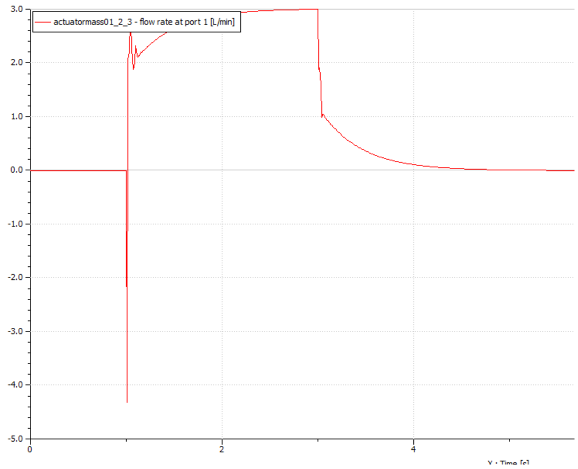
Spool velocity vs. Time

Fig. 5. Simulation results with PD type controller

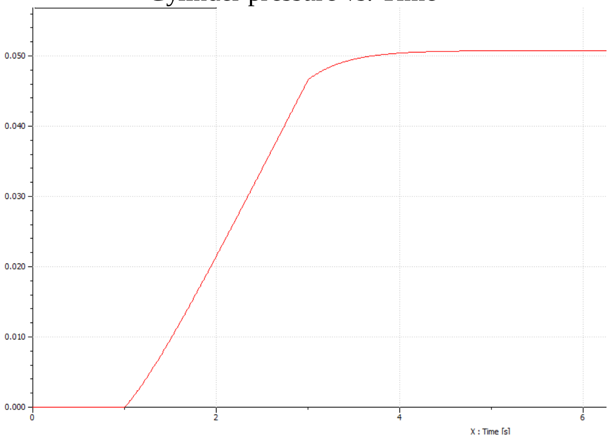
6. PID control



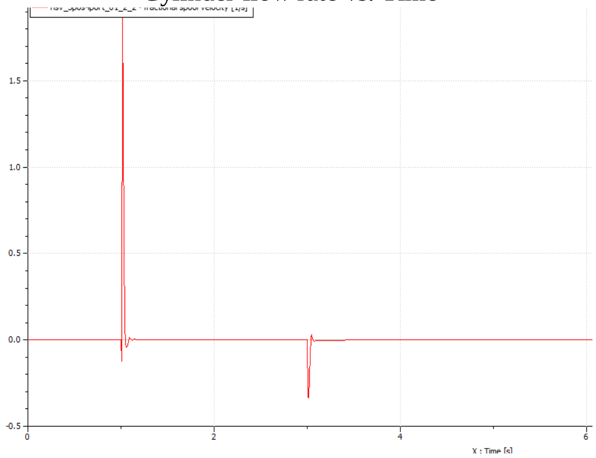
Cylinder pressure vs. Time



Cylinder flow rate vs. Time



Piston displacement vs. Time



Spool velocity vs. Time

Fig. 6. Simulation results with PID type controller

V. Conclusion

The mathematical model of complete hydraulic servo system is developed and simulated. In the simulation Proportional control, PI control, PD control and PID controllers are analyzed and performances of all these controllers are observed from the plots of Cylinder pressure, cylinder flow rate, piston displacement and spool velocity. On the face of similar disturbances, performance of PID controller is found to be smoother, next best smooth controller is PD type.

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