Simulation and Modelling Dynamic Performances of the Servo-Solenoid Directional Valve using Matlab

Dr. Khalaf Hasan Ali

College of Engineering, AMA International University-Bahrain Kingdom of Bahrain
Corresponding Author's Email: khali@amaiu.edu.bh

I. INTRODUCTION

The proportional electrohydraulic servo-solenoid directional valve can be applied with deferent applications, "It is found that in the industrial field and that equipment must satisfy the special requirements of the industrial and mobile installations. They have known an increasing in developing and use of electronics and microprocessors controllers which contributed to the improvement of their dynamic performances of the proportional electrohydraulic servo-solenoid directional valve. The progress registered in the domain of proportional.

Electrohydraulic directional valves enhanced their performances which improve the accuracy of the hydraulic circuit as will reduce the noise and overshoot of the output.

The proportional solenoid valves are used in the application of control in the closed loop with a low price and low cost of maintenance needs. At the proportional solenoid valves, the command force generates the displacement of a spool which modifies the area of certain apertures that control flow and pressure in the system. The change of the area is designed to be approximately linear with the displacement of the spool. The perturbations in the motion of the spool are undesirable which is caused by the friction forces between a spool and the valve body, and the static pressure forces caused by the geometry of the spool or by the inertia forces generated by the flow".

1.1   Statement of the Problem

In the field of the electro-hydraulic control system the performance, including the stability of the system are important parts of the hydraulic system working. In this work, electro-hydraulic control circuits including a proportional directional control valve have been designed. A mathematical model developed to determine the natural frequency and damping ratio of the PEHSV   using Matlab software.

1.2   Significance of the Study

The significant of the study is to Achieving good performance of the Proportional electrohydraulic servo-solenoid directional valve with Appling different range of flow parameters, to enhance the stability of the valves. By reaching this level of resolution, a mathematical model to determine the natural frequency and damping ratio using the Matlab software. Finding out the stability of the system with different input parameters, the derivative (PID controller) control can be used.

1.3 Scope and Limitation

This research will focus on the output parameter of the controller such as time response, stability and another control parameter with respect the hydraulic input parameters The main limitation of this study is that there is no experimental investigation could be performed in the meantime.

1.4   Conceptual Framework / Theoretical Framework

In this research will use the modeling of the performance of   the   servo-solenoid directional valve using Simulink code in MATLAB, to investigate the effect of many like flow rate, oil viscosity, spool area, pressure, and valve time opening parameters on the dynamic performance of the valve in order to enhance the performance of the valve response and stability.

II. LITERATURE REVIEW

Hydraulic system using drives are often used in heavy industries, like a heavy crane to carry a heavy load. In the hydraulic circuit, the main components used for such drive are the cylinder and a proportional valve in this research they will be investigated.

Linear mathematical modelling of the hydraulic system proves to be very useful for a controller determination. Rich. Barton et al. [1] presented at 1998 a simple method to estimate the effect of some parameters such that, spring constant viscous damping coefficient, spring pretension and flow force spring constant on the proportional solenoid valve performance. "This estimation associated with the main stage of a proportional solenoid valve and they found that a

large spool displacement was preferable because information along the complete stroke of the valve could be obtained. In 1999 Zheng D.L. [2] simulates a method for the electro-hydraulic system. Without using directly conventional linear model. Accurate models for the electro-hydraulic components have been constructed using the data provided by the manufactures with measurements obtained in the laboratory, he builds an electro-hydraulic manipulator and by using simulation package, Simulink, the non-linear differential equations were solved. Vaughan N.D and Gamble J.B [3] in 2001, presented models of various configuration to modelling the control of the proportional valves. These models provide an understanding of the interactions between, mechanical, electrical and fluid aspects of hydraulic control valves.

A satisfactory dynamic characteristic may be achieved by using advanced strategies of control, for obtaining the slide which should reduce the influence of the nonlinear conditions of operation of the servo-solenoid valve."

This type of servo-solenoid valves will operate optimally if provided with a controller dedicated with position loop with LVDT sensor [4], [5], [6]. The controller minimizes the effects of the nonlinear perturbations at the displacement of the slide and improves the answer in frequency.
It can be concluded from the above that most of the research in the hydraulic system had chosen one particular controlling or modelling type.

III. RESEARCH METHODOLOGY

This chapter is to explain the research methodology of the mathematical modelling system which can be used to represent physical systems into transfer function equations. MATLAB Simulation can be used to effectively determine the best performance dynamic response.

3.1 Research Design

Mathematical modelling of the valve component will be presented to achieve the performance of the Proportional electrohydraulic servo-solenoid directional valve. A simulation of this model will work by Simulink MATLAB — simulation and Modeling of the hydraulic system, using Matlab-Simulink software to evaluating the theoretical analysis of the actuating system as well as to determine the Simulation result of hydraulic system as a function of the hydraulic component parameters.

3. 2   Modeling of Hydraulic Components

Modelling of hydraulic components has done according to certain assumptions:

a) The valve is symmetrical, and the spool of a valve is ideal with zero lapping,

b) The hydraulic pump is ideal that means it supplies constant pressure ps for the required flow,

c) The pressure of the tank is constant and equal to atmospheric pressure,

d) Dynamic of the hydraulic pipe is neglected

Scheme of double acting hydraulic cylinder controlled by four-way direction valve is shown in Fig.1.The main function of this kind of valve is to direct and distribute flow between cylinders and pump and tank. The system arranged as an open loop. The cylinder drives a load which includes a mass, viscous friction and spring forces.
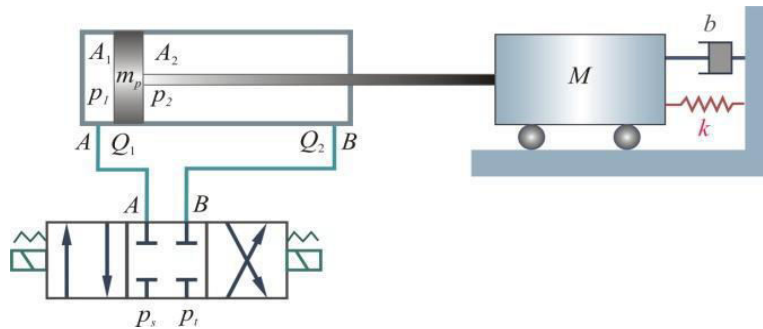

Fig. 1. Schematic diagram of the hydraulic system

3. 2.1   Hydraulic cylinder Modelling

Hydraulic cylinders use the power of a liquid, usually oil, to provide mechanical work – mechanical force and motion. Functionally, cylinders can produce mechanical work in one and both directions during extending and retracting.

$$\Delta p_i = -\frac{\beta}{V_i} \Delta V_i,$$

With component R it is possible to model viscous friction due to piston motion. In reference [18] this component is used for defining maximum piston stroke. When piston approaches to the end of motion value of resistance become very high.

3.2.2 Directional valves Modelling

The main function of the directional valve is to direct and distribute flow between consumers, i.e. between the cylinder and pump and tank from the other side (Fig.1). The 'way' of the valve is modelled by well-known relationship flow-pressure for turbulent flow [13]:

$$Qi = C_d\ Ai\ (2\Delta pi\ /\rho)1/2\ (i=1,2)$$

Where; C_d is the discharge coefficient and ρ is the oil density.

The pressure drop across the valve Δp_i $\quad \Delta p_i = p_s - p_i,\ i = (1,2)$

when oil pressure feds to the chamber or $\Delta p_i = p_i - p_t,\ i = (1,2)$

when the chamber is connected to the tank. The pressure drop is represented by R component in bond graph environment

3.2.3 Solenoid Valve Modeling

The solenoid directional control valve can be operated with a given electric voltage to the coil. The basic formula for electric force is calculated by equation 1 [7].

$$f_e = 2\ \pi\ a\ N\ \beta\ i \tag{1}$$

Where ef is an electric force, a is coil radius, N is coil number, β is magnetic flux, i is electric current. The mechanical energy has resulted in equation 2

$$e_m = 2\ \pi\ a\ N \tag{2}$$

Where e_m is mechanical energy and v is rotation speed.

The voltage law is a calculation in equation 3.

$$L\frac{di}{dt} + Ri + (2N\beta la)\dot{\theta} = e_i(t) \tag{3}$$

3.3   Simulink modelling of the 3-way valve

The Pressure-Compensated 3-Way Flow Control Valve block represents a 3-way pressure-compensated flow control valve as a data-sheet-based model. The valve model includes a variable orifice and a normally closed pressure-control valve, connected in parallel with the orifice. The purpose of the pressure control valve is to maintain a preset pressure differential across the orifice by diverting some flow from port A to the tank (port R) if the pressure differential exceeds the preset value. Port C controls the orifice opening, as shown in the following figure
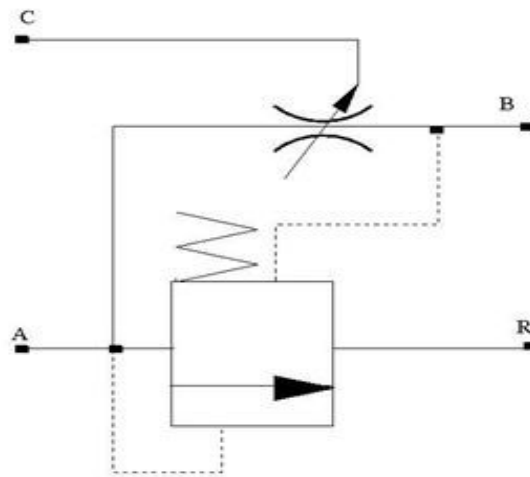
Depending on data listed in the manufacturer's catalogues or data sheets for your particular valve, you can choose one of the following model parameterization options:

By maximum area and opening — Use this option if the data sheet provides only the orifice maximum area and the control member maximum stroke.

By area vs opening table — Use this option if the catalogue or data sheet provides a table of the orifice passage area based on the control member displacement A=A(h).

In the first case, the passage area is assumed to be linearly dependent on the control member displacement, that is, the orifice is assumed to be closed if the initial orifice opening is set to zero and the control member position also equals zero. The maximum orifice opening takes place at

the maximum displacement. In the second case, the passage area is determined by one-dimensional interpolation from the table A=A(h).

The pressure-control valve representation does not account for inertia, friction, or hydraulic forces. The valve has the following area-pressure differential relationship:

$$A_{pc} = \begin{cases} A_{leak} & \text{for } p < p_{set} \\ (p - p_{set}) \dfrac{A_{max\_pc}}{p_{reg}} & \text{for } p_{set} \leq p \leq (p_{set} + p_{reg}) \\ A_{max\_pc} & \text{for } p > (p_{set} + p_{reg}) \end{cases}$$

where

q	Flow rate
p	Pressure differential
p_A, p_B, p_R	Gauge pressures at the block terminals
C_D	Flow discharge coefficient
A	Instantaneous orifice passage area
A_{max}	Orifice maximum area
A_{leak}	Closed orifice leakage area
h_{max}	Control member maximum displacement
x_0	Initial opening
x	Control member displacement from initial position
h	Orifice opening
ρ	Fluid density
v	Fluid kinematic viscosity
p_{cr}	Minimum pressure for turbulent flow
Re_{cr}	Critical Reynolds number
D_H	Instantaneous orifice hydraulic diameter

Both for the variable orifice and the pressure compensator, a small leakage area is assumed to exist even after the orifice is completely closed. Physically, it represents a possible clearance in the closed valve, but the main purpose of the parameter is to maintain numerical integrity of the circuit by preventing a portion of the system from getting isolated after the valve is completely

closed. An isolated or "hanging" part of the system could affect computational efficiency and even cause failure of computation.

After the area has been determined, the block computes the flow rate for both the orifice and the pressure compensator according to the following equation

$$q = C_D \cdot A \sqrt{\frac{2}{\rho}} \cdot \frac{p}{(p^2 + p_{cr}^2)^{1/4}}$$

$$A = \begin{cases} A_{pc} & \text{for pressure compensator} \\ A_{or} & \text{for variable orifice} \end{cases}$$

$$A_{pc} = \begin{cases} h \cdot A_{max}/h_{max} + A_{leak} & \text{for } h > 0 \\ A_{leak} & \text{for } h <= 0 \end{cases}$$

$$h = x_0 + x$$

$$p = \begin{cases} p_A - p_R & \text{for pressure compensator} \\ p_A - p_B & \text{for variable orifice} \end{cases}$$

$$p_{cr} = \frac{\rho}{2} \left(\frac{Re_{cr} \cdot \nu}{C_D \cdot D_H} \right)^2$$

$$D_H = \sqrt{\frac{4A}{\pi}}$$

where

q	Flow rate	h	Orifice opening
p	Pressure differential	ρ	Fluid density
p_A, p_B, p_R	Gauge pressures at the block terminals	ν	Fluid kinematic viscosity
C_D	Flow discharge coefficient	p_{cr}	Minimum pressure for turbulent flow
A	Instantaneous orifice passage area	Re_{cr}	Critical Reynolds number
A_{max}	Orifice maximum area	D_H	Instantaneous orifice hydraulic diameter
h_{max}	Control member maximum displacement		
x_0	Initial opening		
x	Control member displacement from initial position		
h	Orifice opening		

3.4 Simulation Using Simulink in Matlab:

Simulink is a graphical extension to MATLAB for the modelling and simulation of systems. In Simulink, systems are drawn on the screen as block diagrams. Many elements of block diagrams are available (such as transfer functions, summing junctions, etc.), as well as virtual input devices (such as function generators) and output devices (such as oscilloscopes). Simulink is integrated with MATLAB and data can be easily transferred between the programs. In this tutorial, we will introduce the basics of using Simulink to model and simulate a system.

The following schematic represents the model are about to build. It contains a double-acting hydraulic cylinder with a single rod, which is controlled by a high response servo-valve (FESTO). The cylinder drives a load consisting of a mass, damping, and preloaded spring
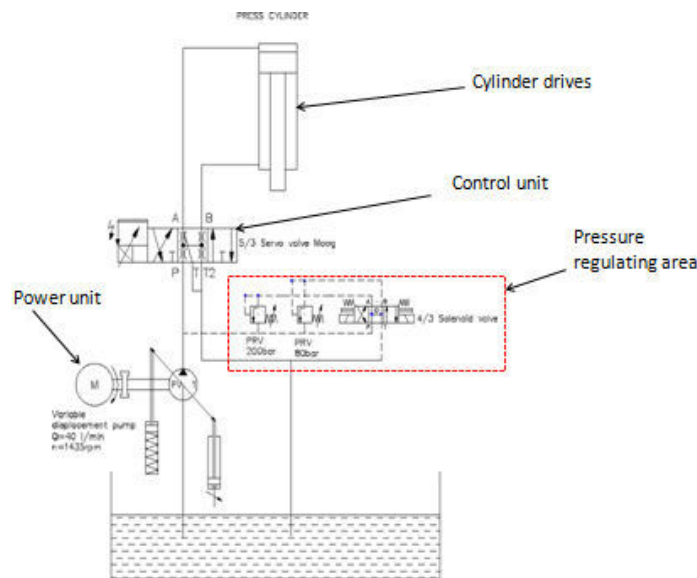
Schematic diagram of a hydraulic circuit

 "A dynamic model of a closed hydraulic system by utilizing the MATLAB-SIMULINK software, the effects of various design parameters on the overall response of the system is investigated. The verification of the simulation results with the experimental studies justifies the proposed dynamic model."

4. RESULT AND DISCUSSION

"Simulation results for controlling the hydraulic circuit response is performed using Matlab Simulink. The described model in chapter 2 was tested with the Simulation parameters are listed in table 4.1, all values are in IS unites".

Table 4.1. Material and geometrical parameters of the hydraulic system

Parameters	Unit	Value
Mass (M)	Kg	40
Spring stiffness coefficient (k)	kN/m	15
The coefficient of viscous friction (b)	Ns/m	150
Piston section ($A1$)	m2	12 e-4
Piston section ($A2$)	m2	9 e-4
Fluid density (ρ)	kg/m3	850
Pressure supply	M Pa	6
Discharge coefficient	(Cd)	0.64
The nominal flow rate of the valve (Q)	l/s	1.2

Figure 4.1 represents the response signal of the time activating signal obtained by the Simulink
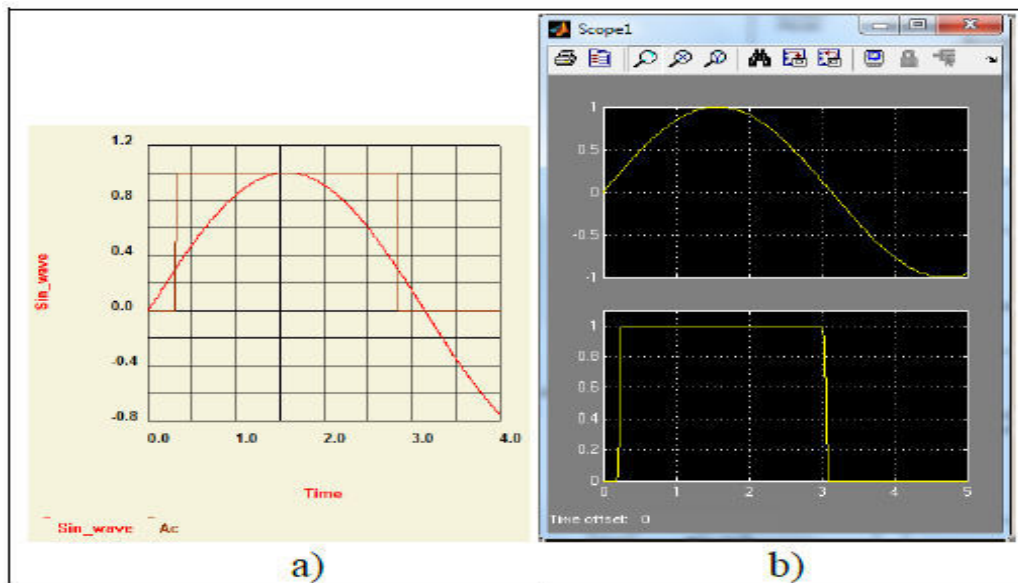

a)   b)

Fig. 4.1 Time histories of activation signals obtained by a) Theoretical; b) MATLAB/Simulink

"It consists of the generator of sine function and actuator which produce activation signal when the amplitude of sine function becomes greater than 0.3, as shown in Fig.4.1. The pump supplies the system with constant

oil pressure and it is represented by source effort SE. Simulation is performed with the time step of 1e-3s and simulation time of 4 s."
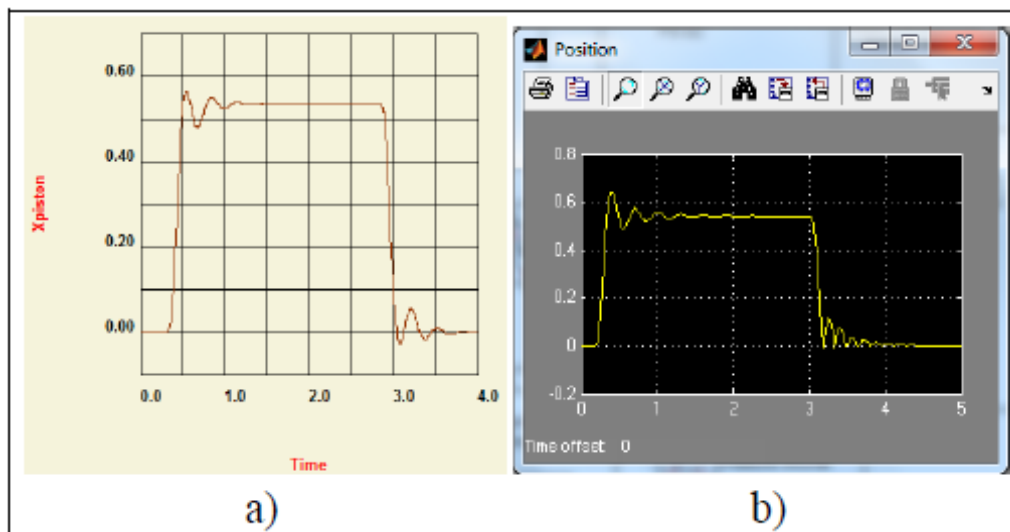

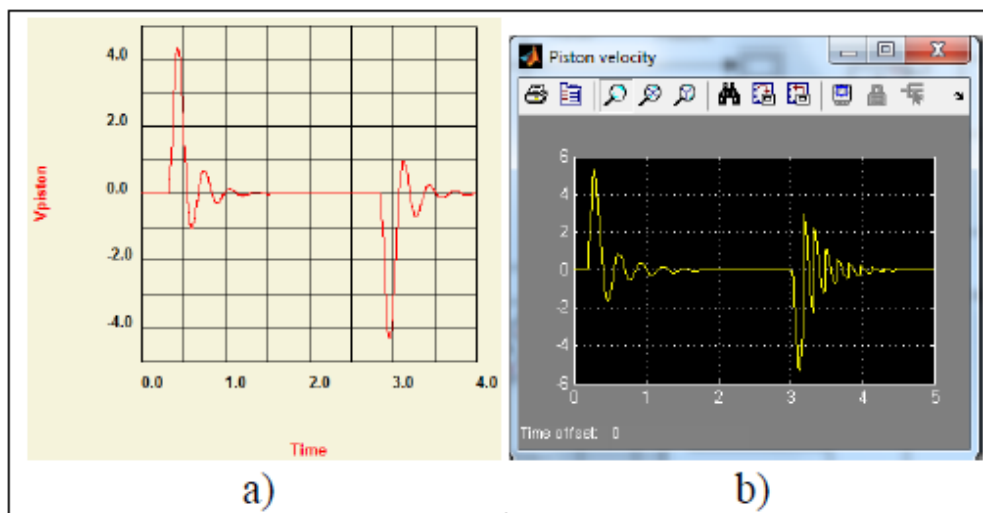Fig. 4.2 The piston position obtained by a) Theory; b) MATLAB/Simulink

Fig. 4.3 The piston velocity obtained by a) Theory; b) MATLAB/Simulink

Simulation results are presented in Fi Simulation is performed with the time step of 1e-3 and simulation time of 4 s.

The validated developed model simulation results are compared with ones obtained using MATLAB/Simulink. It is taken MATLAB/Simulink model from [9] in which values of parameters (from Tab. 1) are entered Figures 4.1-3. Results obtained by bond graph model is in good agreement with ones of MATLAB/Simulink model.

V. CONCLUSION

"This research presents a strategy for modeling and simulation Hydraulic system, which are regularly utilized as means of control transmission in machine instruments, material handling gadgets, versatile machines, etc. Bond graph model of hydraulic system frameworks is created utilizing the program Simulink and recreation come about are compared with comes about gotten utilizing MATLAB/Simulink. The comparison appears great understanding. The proposed approach can be utilized for modeling and reenactment of an exceptionally complex system, which cannot be done for illustration utilizing block diagrams. The inquiry about ought to be amplified on modeling other hydraulic components which pressure driven circuit consists of, for the occasion the other kind of valves (non-return, pressure limiter, etc.). Within the future examinations, the especially consideration will be centered on an examination of different control methods. Moreover, it is interested to extend the examination to the modeling of other subsystems of a complex framework in which water powered circuit is applied, for the occasion the mechanical standard."

REFERENCES

[1] Rich. Bartonetal ,"A Technique of Estimate Some Valve Parameters in Proportional Valve" , Dept. of Mech. Engineering. The University of Saskatchewan, Canada (1998).

[2] Zheng D. li "Modeling and Simulation of an Electro-Hydraulic Mining Manipulator" Dept. of Mech. Engineering. University of Queensland (2000).

[3] Vaughan N.D. and J.B. Gamble "The Modeling and Simulation of Proportional Solenoid Valve" ASME Journal of Dynamic systems, Measurement, and Control (118:120-125), (1999).

[4] *S.H.Cho, M Fiedler, F Rudiger and S Helduser,* Virtual Design Model Based Pressure-

[5] Tracking Control of High-Dynamic Pneumatic valves Using a Sliding Mode Controller

[6] Combined with a Proportional-Integral-Derivative Scheme, Proceedings of the Institution of Mechanical Engineers, 2006

[7] V Radisavljevic, Calculation of feedback gains for an optimal controller, Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering,2000.

[8] Romero, G.; Felez J.; Martinez, M. L. & del Vas, J. J. (2008). Simulation of the hydraulic circuit of a wheel loader by using the Bond Graph technique, Proceedings of 22nd European Conference on Modelling and Simulation ÓECMS, June 3rd - 6th, 2008,

[9] https://www.mathworks.com/products/simulink/examples.html;jsessionid=b97d367fd08fb02ba142a7cc3abe?file=/products/demos/shipping/simulink/sldemo_hydcyl.html, Single Hydraulic Cylinder Simulation, Accessed on 2012-08-01