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Research Article

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Analysis of Solenoid Cartridge Valve in Valve Experiment Assembly

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Abstract In this study, an experiment study was conducted to examine the behaviour of the solenoid cartridge valve in the system. First the velocity and position data were taken in the experiment according to the square wave. In the second part of the experiment, a mathematical model was created using Matlab System Identification Toolbox in Matlab© Simulink©. Position information of the piston was transferred to Simulink through LVDT (Linear Variable Differential Transformer) by the effect of the Solenoid cartridge valve that was driven by square wave. As a result, when the mathematical model and experiment results were compared, the theoretical mathematical equation obtained and the transfer function deduced in the test result were compared and it was seen that the two results converged by 97.11% to each other.

Keywords Cartridge valve, Solenoid valve, Solenoid Cartridge valve

1. Introduction

Solenoid valves are two- or three-way valves that operate on AC or DC electrical energy and function to control various fluid lines. The control of the fluid line is effected by the electromagnetic force. Solenoid valves are divided into two groups; normally open and normally closed. When the coil is powered, the valves that are used to open the closed line are called as normally closed, while the valves that are used to close the open line when the coil is powered is called as the normally open solenoid valve.

The following information was obtained in the literature review. Experiment study was guided under the light of this information.

Heon et al. conducted a study on pressure control with the PWM signal of a hydraulic 3-way open/closed solenoid valve. They used a computer controlled pressure controller, a DAC card (i80C196) that can generate PWM signals, an open/closed solenoid valve and a pressure sensor [1].

Gab et al. produced an intelligent robot's gripper pincer that provides six-axis force and moment control. They used Mitsubishi engine (HC-MF 13), motor driver (MR-J2-10A), DAC (8251A PCI) card, DSP (TMS320C32PCM50) card and F/M (N2A-13-T001N-350) sensor in the experiment assembly. They compared the theoretical calculation results and the experiment results. The highest error was calculated to be 2,79-6% [2].

Cheng et al. have studied position control with fuzzy logic theory of the synchronous hydraulic cylinders. They used two cylinders, two proportional valves, a hydraulic power unit and a potentiometer in their experiments. They also placed equal loads (210 kg) on the cylinder. They used PCI-1602 DAQ card and PIO-DA8 D / A card in their experiments. They had a tolerance of ± 5 mm in the test results [3].

Doğramacı has modelled it with hydraulic system simulation software AMESLM by creating the mathematical model of the direct-acting pressure relief valves. He showed through the graphs the importance and effect of damping in relief valves. He studied the effect of different forms in the relief valve bar on "pressure overlay". With this study, it was concluded that the number of prototypes can be reduced by previously determining by the computer program what kind of opening characteristic will be achieved and whether it would cause vibration before the valves are produced when designing the relief valve [4].

Tian and his team studied the 2-way cartridge valve structure and simulated it in the AMESİM program. The orthogonal test was applied to the valve by applying different spring hardnesses. Valve permeability according to different spring hardness was observed according to time. In this study, a previously untested method on valve structure was applied. The importance of optimization of bow characteristics was emphasized [5].

2. Solenoid Cartridge Valve

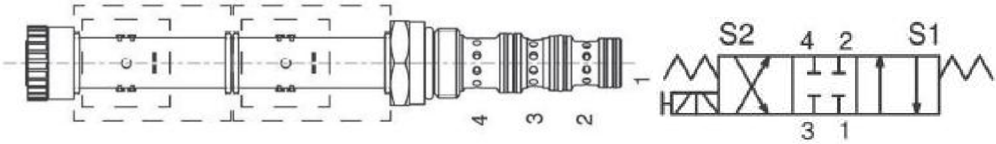

Figure 1: Solenoid cartridge valve and its view

Figure 1 includes the general structure and schematic representation of the solenoid solenoid valve is given. Cartridge valves are known to be structurally different from known solenoid valves.

In this study, WINMAN brand WSV10-43-A 24DC model solenoid cartridge valve was used. The highest working pressure of the valve is 250 bar. Valve operation flow is 20 lt/min. This flow is reached at 7 bar at the highest. The valve is normally a closed centre. This valve is mounted on the system with a special block with pressure relief valve on it.

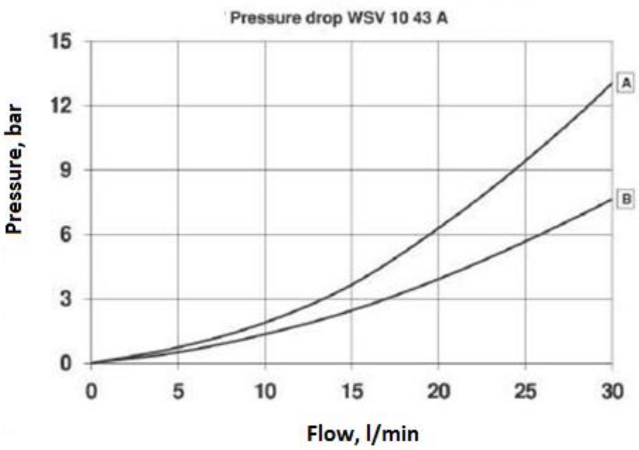

Figure 2: Solenoid valve hydraulic pressure-flow graph (Winman WSV10-43-A catalogue)

3. Method

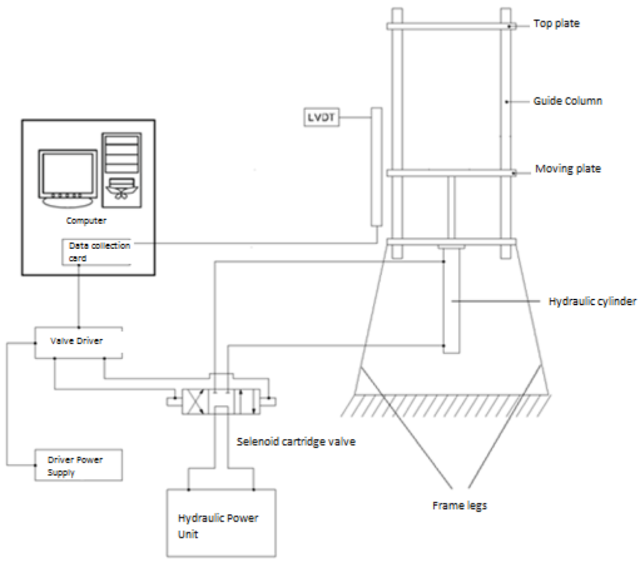

Figure 3: Experiment Assembly Representation

3.1. Experiment Studies for Solenoid Cartridge Valve

Since it is very difficult to theoretically calculate the values in the Solenoid Cartridge Valve experiment studies, it is preferable to record the response of the system to the reference requests and to process the input and output in a suitable environment to remove a transfer function representing the system [6].

The experiment assembly is as shown in the schematic in figure 3. Figure 4 shows the Solenoid Cartridge Valve.

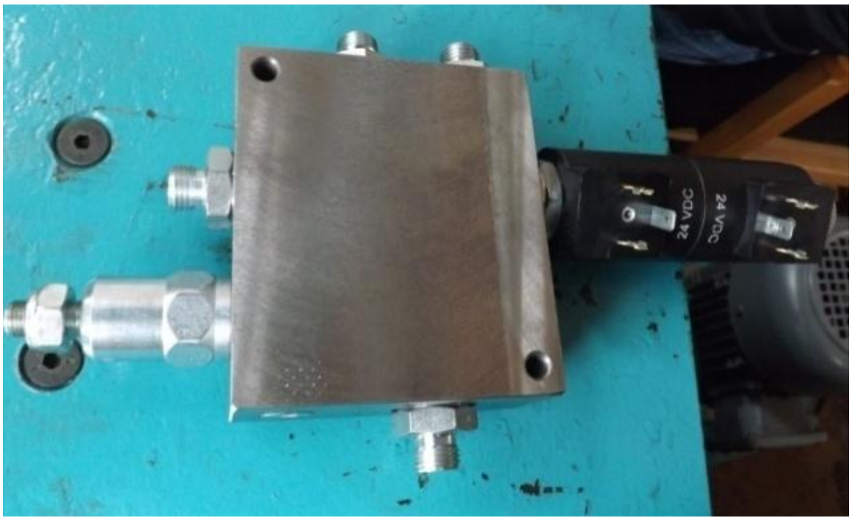

Figure 4: Solenoid Cartridge Valve and Block

In the experiment, square waves with amplitude 16V, frequency 0.5-1-1.5-2-2.5 rad/s were used as request signal. Separate graphs were created for each of these square waves, and interpreted on a single graph in the result section.

Separate transfer functions were obtained for both directions in the experiment studies as the two surfaces of the piston are different from each other in shape. In the forward direction, the system is driven with a default square wave to ensure that it never receives a negative value, and vice versa. Thus, the square wave fluctuates between 0-16V. The request signal and the corresponding output signal are shown in Fig. 5.

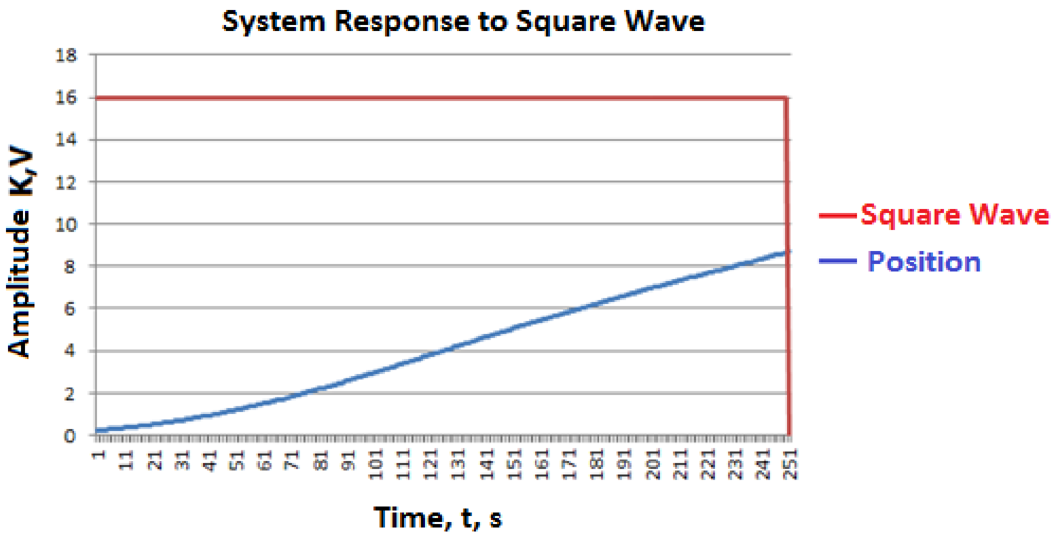

Figure 5: System Response to Square Wave

The Ident interface within the System Identification Toolbox module of the MATLAB software was used for the diagnostic study.

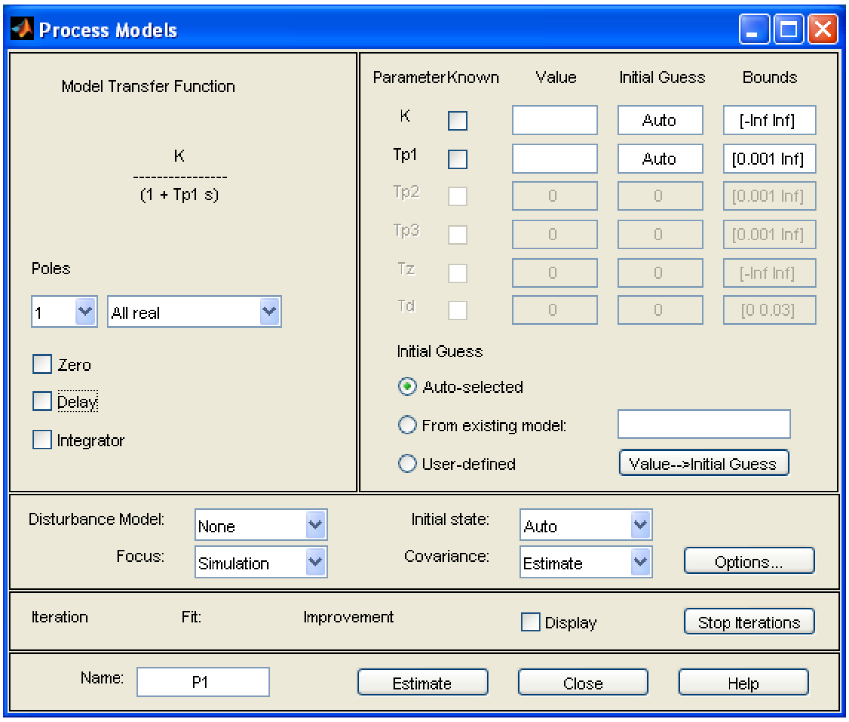

Figure 6: Transfer Function Deduction Model

The request signal and slider position information were loaded into the Ident program for diagnosis.

"Process Model" was selected among the options shown in Figure 6 since this study intended to express the system by a transfer function. This method adapts optionally a type zero or type one transfer function with a first or second grade denominator and a zero or first grade numerator to the given request and response.

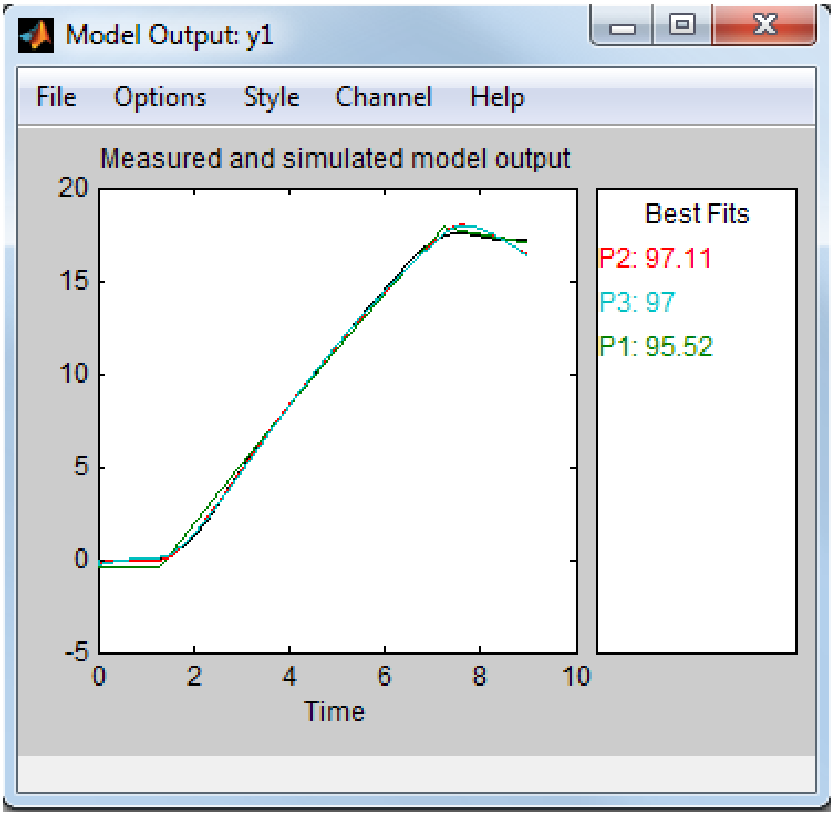

Figure 7: The system response to square wave and transfer function convergence

It is understood from the test data graph given in Figure 7 that the second and third grade valve dynamics have a higher grade system characteristic than the first grade. For simplicity of analysis and for clarity and usefulness of the transfer function obtained, it would be appropriate to use a first-grade transfer function including the dominant poles of the system. The transfer function was obtained in line of the results obtained from the analysis.

$$\frac{Y_{(s)}}{X_{(s)}} = \frac{-9{,}095e-0{,}13s^2 - 9{,}095e-0{,}13s + 6800}{s^3 + 1002s^2 + 1606s + 196{,}5} \quad [1]$$

This function defines the system with an accuracy of 97,11% as shown in the figure.

The open loop transfer function can be calculated theoretically very simply from this closed loop transfer function.

Here,

U (s): Request signal,

Y (s): Piston position,

C (s): LVDT transfer function,

T (s): System closed loop transfer function,

G (s): The system open loop transfer function,

$$G_{(s)} = \frac{T_{(s)}}{C_{(s)} - C_{(s)}T_{(s)}} \quad [2]$$

$$G_{(s)} = \frac{\dfrac{0{,}7837}{s^2 + 3{,}853s + 1{,}011\times10^{-5}}}{1 - \dfrac{0{,}7837}{s^2 + 3{,}853s + 1{,}011\times10^{-5}}} \quad [3]$$

$$G_{(s)} = \frac{0{,}7837}{s^2 + 3{,}853s - 0{,}78368989} \quad [4]$$

The above transfer function was used in Matlab/Simulink environment and the system response was simulated in PC environment. Figure 8 shows the block diagram created in Simulink. The request signal and the piston position are shown in Figure 8.

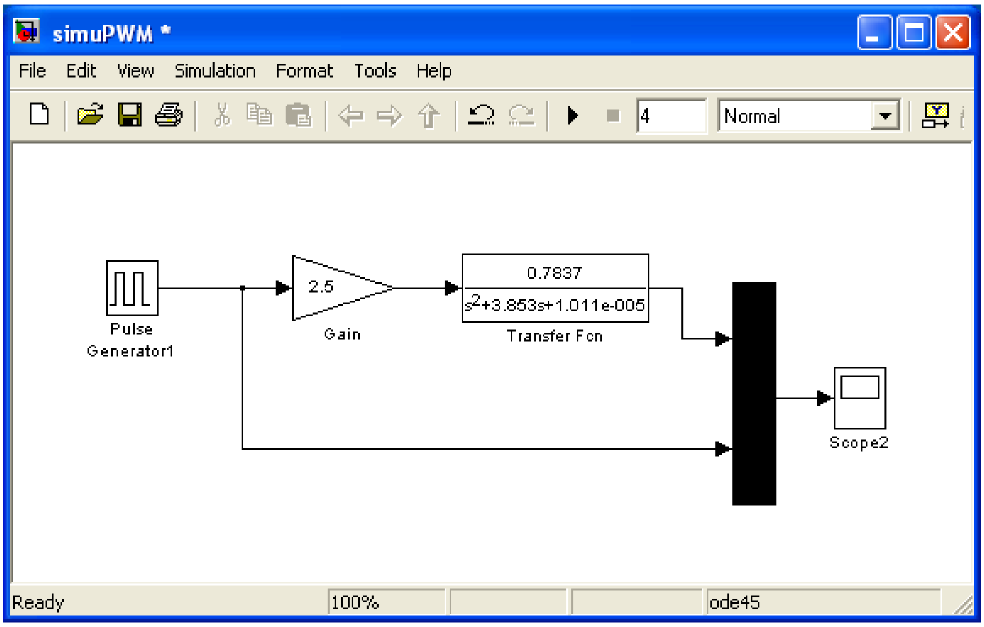

Figure 8: Matlab/simulink environment

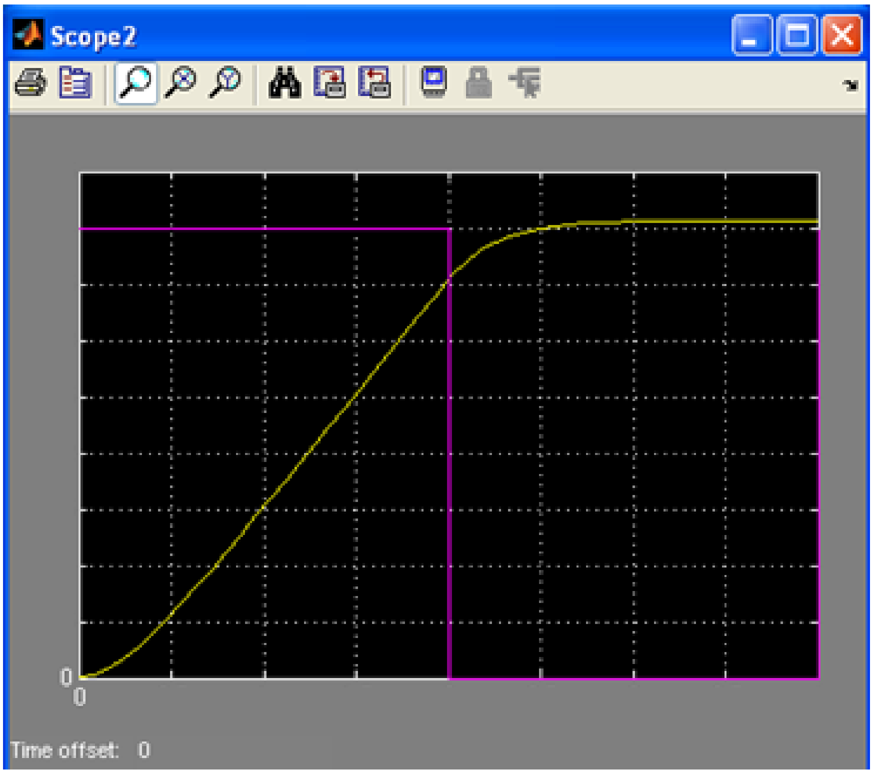

Figure 9: Matlab/simulink Square wave and system response

Then the same signal was applied to the piston in real time. The block diagram created in Simulink is shown in Figure 10. The request signal and the piston position are shown in Figure 11.

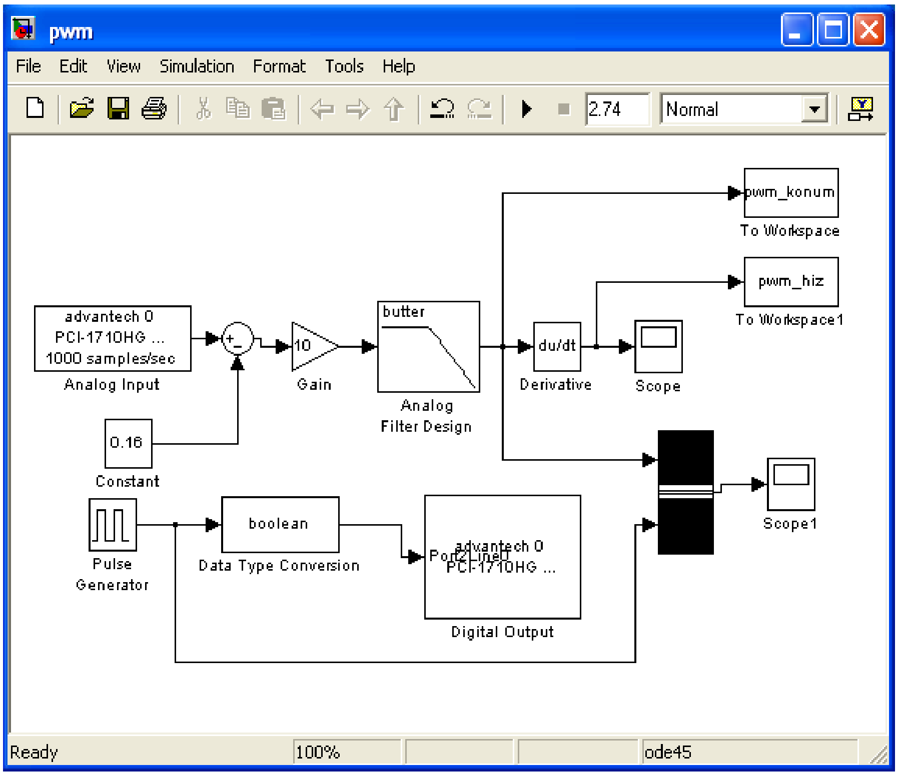

Figure 10: Matlab/simulink environment (blocks providing real-time piston movement)

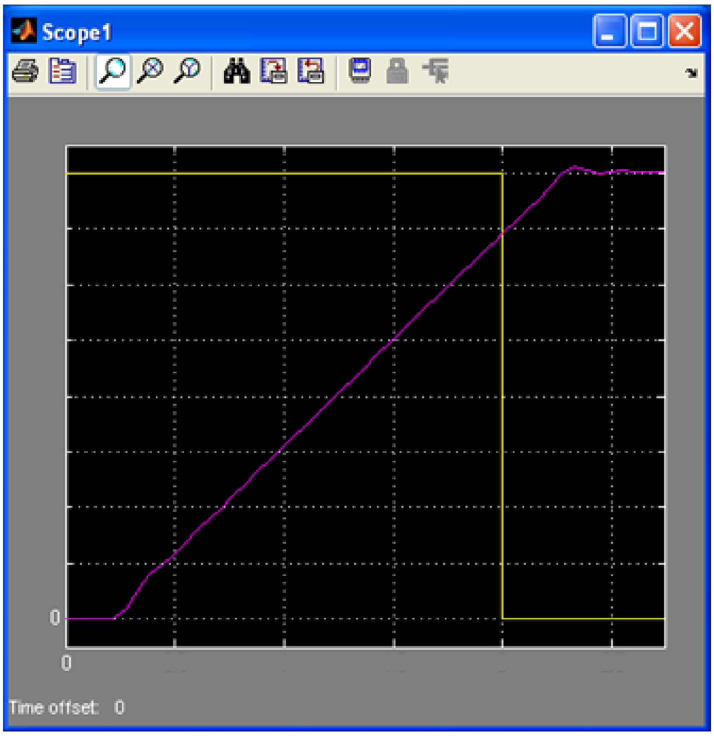

Figure 11: Matlab/simulink real-time square wave and system response

3.2. Mathematical Model

The output signals corresponding to the request signal was addressed and the transfer function to express the system was created through a mathematical model using Matlab System Identification Toolbox. With this model, the slider dynamics of the valve during testing will be considered entirely.

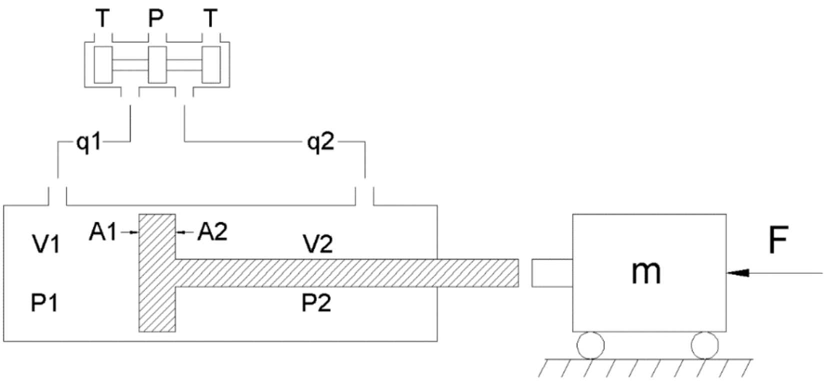

Figure 12: Physical Model of the System

3.2.1. Valve dynamics

The equations that characterize the flow to the q1 and q2 sections of the cylinder can be expressed as follows when, the frictions and leaks in the valve are ignored.
[7] (Equations 5, 6, 7, 8, 9, 10).

$$q_1 = \begin{cases} for\ u \geq 0\,, & k_1 u\sqrt{P - P_1} \\ for\ u < 0\,, & k_2 u\sqrt{P_1 - T} \end{cases} \quad [5]$$

$$q_2 = \begin{cases} for\ u \geq 0, & -\ k_3 u\sqrt{P_2 - T} \\ for\ u < 0, & -\ k_2 u\sqrt{P - P_2} \end{cases} \quad [6]$$

k1, k2, k3 and k4 are valve orifice constants.

The linearized valve dynamic is as follows;

$$Q_L = K_q x_v - K_c P_L \quad [7]$$

$$K_q = k_v c_d \omega \sqrt{\frac{1}{\rho}} \sqrt{P_s - sgn(x_v) P_L} \quad [8]$$

$$P_L = P_1 - P_2 \quad [9]$$

The transfer function of the position dynamics of the valve orifice versus the input current;

$$\frac{Y(s)}{I(s)} = \frac{K_q \omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2} \quad [10]$$

3.2.2. Piston Dynamics

Equation of the motion of the piston according to Newton's second motion law

$$m\ddot{x} = P_1 A_1 - P_2 A_2 - f_u \dot{x} - F \quad [11]$$

When we consider the voltage given to the proportional valve as the input and the position of the piston as the output with these equations, the transfer function [6]

$$\frac{Y(s)}{R(s)} = \frac{K_q \omega_n^2}{As^3 + 2\zeta\omega_n As^2 + A\omega_n^2 s + K_q \omega_n^2 K_{tk}} \quad [12]$$

4. Results and Recommendations

PID signals were applied to the system in different frequency ranges in the Solenoid Cartridge Valve experiment assembly and separate results were obtained. The velocity and position information of the system were obtained separately with the application of the square wave signal at different frequencies. The graphs below show the velocity and position information of the system against the applied frequencies. In other words, the response given by the system as velocity and position against different square wave signals we sent is collected in a single graph. Figure 13 shows the velocity information of the system, and Figure 14 shows the position information of the system.

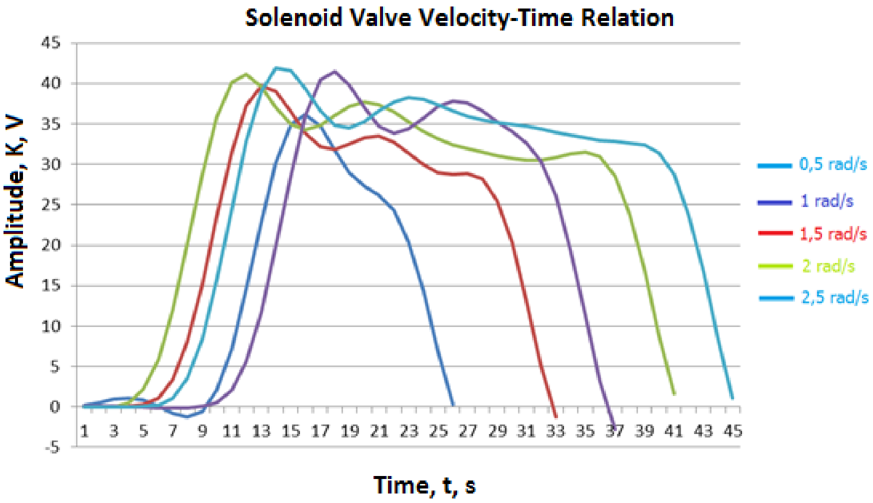

Figure 13: Solenoid valve velocity graph

In Figure 13, the solenoid valve velocity-time graph shows the response results of the system to the square wave signal as velocity. Solenoid valves are frequently used in hydraulic system applications. In general, they perform the opening and closing tasks in the system. Due to their task, they have to respond quickly to the signal applied. The solenoid valves fall into momentary instabilities at the peak point to reach the opening closing velocity of the square wave, but they are just able to catch the open-door frequency.

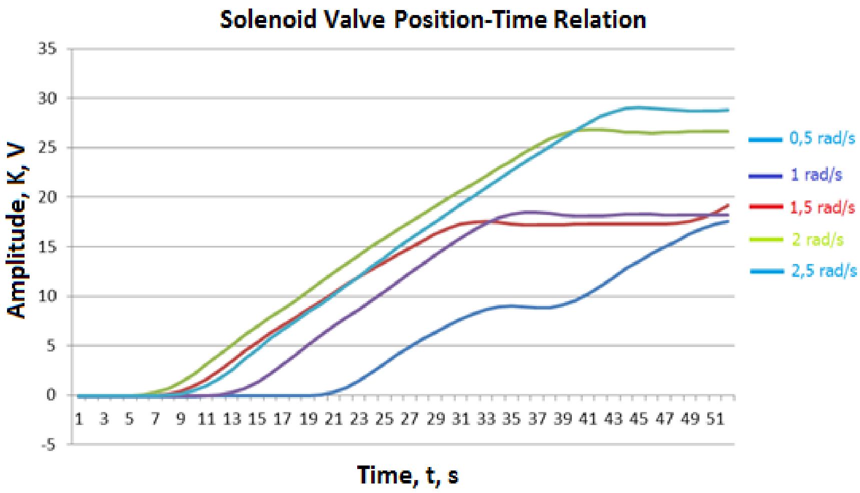

Figure 14: Solenoid valve position graph

In Figure 14, the position information of the system is given according to the frequencies applied in the position-time graph of the solenoid valve. The positions were steadily similar in the systems where various frequencies were applied. The position information differs according to the frequency value of the applied signal. It is seen that the position information when the applied frequency is large is more stable.

Experiment assembly designed and manufactured for the study; the specification of hydraulic valve standards are important for the control of hydraulic valves with standards. This experiment assembly is a value gained for our country and will be available for all subsequent hydraulic valve experiments.

In this study, mathematical models of solenoid and proportional cartridge valves which have not been studied previously have been created and the experiments have been successfully performed. Comparing the mathematical model to the experiment results, convergence of the solenoid cartridge valve at a ratio of 97,11% was observed.

It is expected that this study will be a guidance for future studies.

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