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BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **MODELING, SIMULATION AND EXPERIMENTAL VERIFICATION OF HYDRAULIC SERVO SYSTEM**

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MODELING, SIMULATION AND EXPERIMENTAL VERIFICATION OF HYDRAULIC SERVO SYSTEM

ANIS SYARLIZA BINTI AHMAD

A report submitted in partial fulfillment of the requirements

for the award of the degree of

Bachelor of Mechatronic Engineering

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EXAMINER APPROVAL DOCUMENT

We certify that the thesis entitled “MODELING, SIMULATION AND EXPERIMENTAL VERIFICATION OF HYDRAULIC SERVO SYSTEM” is written by ANIS SYARLIZA BINTI AHMAD. We have examined the final copy of this thesis and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Engineering in Mechatronic. We herewith recommend that it be accepted in fulfillment of the requirement for the degree of Engineering specializing in Mechatronic.

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SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project report and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechatronic Engineering

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STUDENT'S DECLARATION

I hereby declare that the work in this report entitles "Modeling, Simulation and Experimental Verification of Hydraulic Servo System" is the results of my own research except as cited in the references. The project has not been accepted for any degree and is not concurrently submitted for award of the other degree.

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Dedicated to my beloved father, Ahmad Bin Ishak,

Mother, Noryati Binti Ibrahim, brothers

And

My supervisor, Prof Madya Dr Wan Azhar bin Wan Yusoff

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ABSTRACT

The aim of this project is to model, simulate and analyze the performance of the hydraulic servo system using MATLAB and Simulink. Experiments were conducted using open loop and closed loop control. In open loop control, the experiment was conducted for various speeds by supplying voltage to actuator from 5V to 10V. The open loop experimental data were used to determine the transfer function of the system. In closed loop control, the PI, PD and PID controllers were implemented in the hydraulic servo system and the desired positions were set to 30 mm, 50 mm and 70 mm. The results of the closed loop control showed that the PID controller produced better performance. The results also indicate that the transfer function model represented the actual system very well.

ABSTRAK

Tujuan projek ini adalah untuk model, simulasi dan menganalisis prestasi sistem servo hidraulik menggunakan MATLAB dan Simulink. Eksperimen telah dijalankan menggunakan kawalan loop terbuka dan kawalan loop tertutup. Dalam kawalan loop terbuka, eksperimen telah dijalankan untuk pelbagai kelajuan dengan membekalkan voltan kepada penggerak dari 5V ke 10V. Data eksperimen kawalan loop terbuka telah digunakan untuk menentukan fungsi pindah sistem. Dalam kawalan loop tertutup, pengawal PI, PD dan PID telah dilaksanakan dalam sistem servo hidraulik dan kedudukan yang telah ditetapkan kepada 30 mm, 50 mm dan 70 mm. Keputusan kawalan loop tertutup menunjukkan bahawa pengawal PID menghasilkan prestasi yang lebih baik. Keputusan juga menunjukkan bahawa model fungsi pindah mewakili sistem sebenar dengan baik.

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PID	Proportional, Integral Derivative
DAQ	Data Acquisition

CHAPTER 1

INTRODUCTION

1.1 PROJECT MOTIVATION

The hydraulic servo system has the capabilities of providing large driving force and torques and higher speed of response with fast motion. This makes hydraulic servo system widely used in modern industrial applications. Hydraulic Servo Shaker is one of the application hydraulic servo systems. It was used in testing car suspension system to ensure that the suspension system can efficiently absorb the pushdown force when pass through uneven road. It will test the dampers, torsion bars, springs as well as car suspension to optimize the performance of the system. It will simulate chassis vertical dynamic as vehicle travel on rough roads by generating a force at tire contact patches using electro hydraulic servo actuators.

However, it is a non-linear system and causes this system difficult to control. In recent research, many researchers studied the dynamic characteristic of a hydraulic servo system for the purpose controlling the system. Some of them had designed and implemented a control system for operation of high-speed non-linear hydraulic servo system (D. Maneetham, 2009; N. Afzulpurkar, 2009). However, it is hard to analyze the parameter of hydraulic system by theoretically. To solve this, it is required to find the transfer function of hydraulic servo system (J.C Koo et al, 2012). The transfer function is a frequency domain equation that represents a system. Transfer function is used to model a system and to further analyze the system.

Modeling is a process of producing a model that represents working or the response of a system. Modeling often used to estimate unknown parameters. Sometimes, the system is complicated to derive the model directly from physical laws. Modeling will present as block diagrams for simulation. Simulation is an operation of a model of the system. Simulation is used to test the system before it applies in real system. This is to reduce the chances of failures to meet specifications required by a system (Anu Maria, 1997). In further analysis, simulation will help researcher to design the controller for a system. In this project, the control system of hydraulic servo system is build and applies to the hydraulic servo shaker to optimize the performance.

1.2 PROJECT BACKGROUND

The hydraulic servo system is a complex system to understand its dynamic characteristic of the system (J. Shao et al, 2009). It has a non-linear dynamic system. The non-linear dynamic system is a system, which is the output, is not directly proportional to its input. This may cause the system difficult to control. Dynamic system is a system theory that helps to understand the dynamic behavior of a system (Harold and Randal, 2011). Studying on dynamic system is an approach to understand the behavior of complex system and thus, designing a controller for a system. Designing a controller for a system required transfer function of a system so that it can analyze the dynamic behavior using modeling the transfer function. Modeling and simulating in software can help to determine the characteristic of the system and indirectly can optimize the dynamic performance of the system.

This research is studying about hydraulic servo shaker that is a system that used for shaking a structure placed by the structure, which is a specimen under test on the actuator. The shaker will generate oscillation motion to produce vibration to test the structure. Oscillatory motion applies to tires as to see how the suspension system adaptable when pass through uneven road. To produce the efficient tester of a shaker, the actuator of hydraulic servo shaker must be control its speed and motion. Modeling and simulating the system can optimize the hydraulic servo shaker by testing the system in the virtual system.

1.3 PROBLEM STATEMENT

The hydraulic servo system is an electrically operated valve that control how hydraulic fluid ported to an actuator. Servo valve operates by transforming the analog or digital signal into a smooth set of movement in hydraulic cylinder. This system combined two control modes of electrical and mechanical. However, the dynamic of hydraulic servo system is highly nonlinear and cause this system difficult to control. Non-linear system also may cause the system to be non-smooth and discontinuous due to directional change of valve opening, friction and valve overlap (Y. Hong et. al, 2004). Mathematical model of a system will use to model and simulate the system (Dechrit, 2009; Nitin, 2009). Modeling and simulation is to optimize the dynamic performance by controlling the speed and displacement of the actuator.

This project will study on the characteristic of dynamic system performance of a hydraulic servo system by using modeling and simulating in MATLAB and Simulink. The transfer function of the system will develop for modeling and simulating in MATLAB and Simulink. Hydraulic servo shaker will move with various speeds of piston motion. The characteristics of hydraulic servo system is studied based on data from hydraulic servo shaker. Displacement sensor was mounted to the hydraulic piston for measuring piston motion. The data will be collected by using data acquisition. The hydraulic servo shaker will run by a driver circuit of hydraulic with command from programming. This research also applied open loop and closed loop control during conducting experiments. For closed loop control, there will compare the performance of the system based on PD, PI, and PID controller.

1.4 PROJECT OBJECTIVE

1) To collect and analyze data of hydraulic servo shaker to study the dynamic system of hydraulic servo system.
2) To develop mathematical models of a hydraulic servo system.
3) To model and simulates a hydraulic servo system for studying dynamic characteristics of the system.
4) To compare the analysis dynamic characteristic of a hydraulic servo system in system model and hydraulic servo shaker.
5) To apply of PD, PI and PID controller in the hydraulic servo system and compares the performance of the system.

1.5 PROJECT REPORT ORGANIZATION

This thesis contains five chapters. The descriptions of each chapter are below:

a) Chapter 2 is about the literature review of the thesis**.** It will state the problem statement and methodology and the journals referred to complete this research.
b) Chapter 3 presents about the methodology of a thesis. This chapter will describe the method or procedure to design the experiment and analyze the data. This chapter will describe how to conduct the experiment for collecting data of the hydraulic servo shaker.
c) Chapter 4 is showing the simulation results and analysis of data using MATLAB and Simulink. This simulation will identify the performance of the dynamic system. The data in an open loop system and closed loop system of hydraulic shaker also will present in this chapter.
d) Chapter 5 concludes and gives some suggestion for the future works.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The hydraulic servo system is an electrically operated valve that controls the hydraulic fluid, which is ported to an actuator system. A valve is a device in the hydraulic system, which controls the flow of the hydraulic fluid. The hydraulic servo system has the abilities to apply very large forces and torques, thus, it was being applied widely in heavy industry. Besides that, it also has high stiffness and fast response for heavy industry. Some applications of hydraulic servo system in heavy industrial are in automotive, construction machinery, lifting and conveying devices (D. Markle et al, 1998). However, electro hydraulic servo system is typically a non-linear system. It causes the system difficult to control due to problems with high non-linearity and motion friction (J. Shao et al, 2009).

Non-linear system is a system, which is the output, is not directly proportional to its input. Therefore, for some applications these systems are difficult for accurate control. A non-linear phenomenon may cause non-smooth and discontinuous nonlinearities due to directional change of valve opening, friction and valve overlap (B. Yao et. al, 1998). Thus, there are many previous researchers had studied the dynamic characteristic of a hydraulic servo system to develop a controller for this system. The designed controller must work properly with dealing the non-linear phenomenon and dynamic of the hydraulic servo system parameters (Dcehrit, 2009; Nitin, 2009).

2.2 HYDRAULIC SERVO SYSTEM

Hydraulic servo system will refers to the control system, which combines two modes of control of electric and hydraulic. Load driving and hydraulic transmission in hydraulic servo system will control by detecting transmitting, and processing the signal by using electric and electronic components (J. Cheng et. al, 2011). The servo is a control system, that can measure its own output and forces the output for system follow a command signal quickly and accurately. The effect on incidence when the actual result under a given set of assumptions is different from the expected result in control device and the load can be minimized as well as external disturbances in this system. Figure 2.1 shows the basic servomechanism (Karl Erik, 2008).

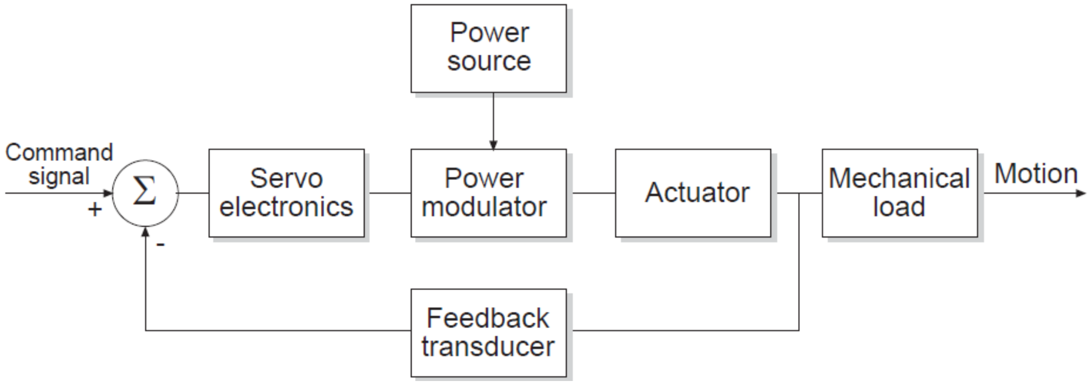

Figure 2.1: Basic servomechanism (Karl Erik, 2008)

Hydraulic servo system, which is an electrical signal, control and regulate hydraulic fluid with pressure to moving the piston. Servo valves will appropriately port a portion of hydraulic fluid flow based on hydraulic power supply. This fluid will drive the actuators to move in the desired direction. A position transducer that gives electric signals in voltage as output measures actuator. The output voltage will control the servo valve to move the actuator to desired position. However, due to hydraulic servo system is non-linear system, there may cause the system non-smooth and discontinuous due to directional change of valve opening and friction.

In the previous research, hydraulic servo system was studied based on their dynamic characteristics. This is for the purpose to study the characteristic of hydraulic servo system response for position control. (J. Shao et. al, 2009) were studied on model identification and control of electro hydraulic position servo system. They worked on mathematical models and carried out hardware-in-loop simulation environment in Real Time Workshop (RTW) and system identification toolbox in MATLAB. As this system is complicated to study, researcher will prefer to model and simulate the system in MATLAB and Simulink. Nevertheless, a mathematical equation is required to model the system.

2.3 MATHEMATICAL EQUATION

The mathematical equation is a description of the system by using mathematical concepts and language. Mathematical equation of servo valves can be developed by the relationship between the displacement and input voltage for the proportional valves (D. Maneetham, 2009; N. Afzulpurkar, 2009). They had described a mathematical model of hydraulic mini press machine. The system consists of high speed, electronic drives, hydraulic actuators and position transducer. Based on basic theory of the hydraulic servo system, the transfer function can be found by simplifying the mathematical equation of each part (J. Shao et. al, 2009). Transfer function also known as the system function is a mathematical representation of the relation between input and output of a system.

In another studied, (J. Cheng et. al, 2011) they were stated the basic equation of a hydraulic servo system that later will simplify into transfer function. They studied asymmetrical cylinder position control of a hydraulic servo system that is used four - way slide valve. Figure 2.2 shows the servo valve controlled asymmetrical cylinder position control system diagram. The diagram notified how hydraulic servo valve operates. Hydraulic servo valve is a valve that is control of the output current signal from the servo amplifier in the system. The actuator or load position will measure by position transducer and gives signals in voltage as output. The mathematical equation of this system will develop using basic theory of hydraulic servo valve that involves flow rate in valve, pressure and actuator or piston motion.

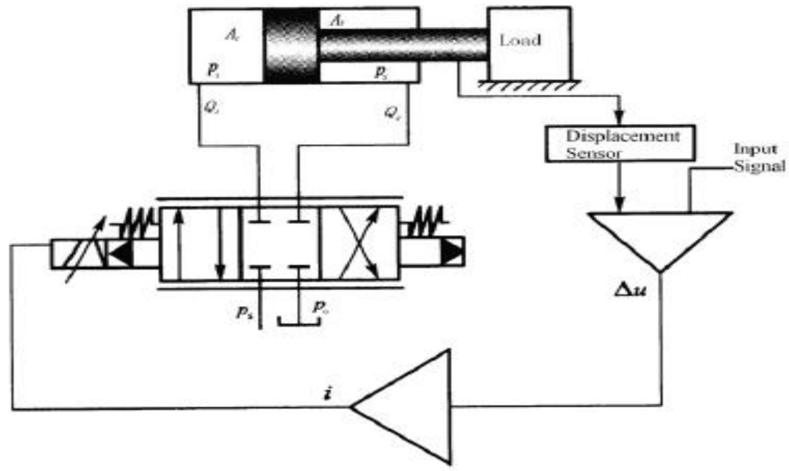

Figure 2.2: The servo valve controlled asymmetrical cylinder position control system (J. Cheng et. al, 2011).

Besides, to develop mathematical equation, it is required to determine the parameters of the system. In past studied, they had stated the basic equation that will used to simplify into transfer function.

The three basic equations of valve control of the hydraulic cylinder system are:

a) Flow equation of four-way valves:

$$Q_L = K_q X_v - K_c P_L$$

b) Equation of load flow continuity of the cylinder:

$$Q_L = C_{tc} P_L + A_p sX_p + \frac{V_t}{4\beta e} sP_L$$

c) Equation of force balance that affected the piston:

$$F_g = P_L A_p = m_t s^2 X_p + (B_p + b) X_p$$

By integrating all the equations above, then it will deduce to the transfer function. The transfer function of this system is the relationship between output and input. Displacement of the piston is an output while the input is the voltage of the system.

$$\frac{X_p}{X_v} = \frac{K_q}{A_p} \cdot \frac{1}{s\left(\frac{s^2}{\omega_h^2}\right) + s\left(\frac{2\zeta_h}{\omega_h}\right) + 1}$$

Where;

$$\omega_h = \sqrt{\frac{4\beta_e A_p^2}{m_t V_t}},$$

$$\zeta_h = \sqrt{\frac{\beta_e m_t}{V_t}} \cdot \frac{K_{ce}}{A_p} + \sqrt{\frac{V_t}{\beta_e m_t}} \cdot \frac{B_p + b}{4A_p}$$

Transfer function above is a second order system that is for position control. However, for controlling the speed of system, it requires a first order transfer function. Transfer function is an important for studying behaviors of hydraulic servo system. Furthermore, transfer function also required to develop control system. The analysis of dynamic system can be further analyzed by modeling using transfer function that obtained. The list of variable symbols of equations was given in Table 2.1.

Table 2.1: List of Variables

Symbol	Name
Q_L	Load flow
K_q	Flow gain
X_v	Input voltage
K_c	Pressure gain coefficient
P_L	Pressure load
C_{tc}	Total leakage coefficient
A_p	Piston area
X_p	Position Piston
β_e	Effective modulus
V_t	Total actuator volume
F_g	Force balance
m_t	Mass Actuator
B_p	Viscous damping coefficient
ζ_h	Damping coefficient

2.4 MODELING

Modeling is defined as a process producing a prototype of the system in software, which is purpose to study the dynamic, or the behavior of a system. Dynamic system behaviors can be explained by mathematical equations and formulae those scientific principles, empirical observations, or both that related to the system (Harold and Randal, 2011). Mathematical equation of the system will use to develop system models by using experimental data of hydraulic servo system.

Modeling of a hydraulic portion of valve and actuator of hydraulic servo system is quite complex due to the large number of lumped parameters. The parameters that will use to describe the system such as supply and return pressure supply, fluid flow supply and return valves. The model must make some assumptions to simplify the modeling process. Normally, research will assume that the flow of fluid in and out of the valves is same and the leakage is negligible in the piston. Modeling is usually for the purpose of study the dynamic behavior of the system. As a complex system, hydraulic servo shaker is difficult to study its external system, modeling will help to understand the external system of it.

M.A Sharifi K. modeled hydraulic servo system for position control that consists of double acting, double ended actuator and four way servo valves. He was initially modelled and then he modified the model according to data derived and makes some simplifying hypothesis for the system. Besides that, the parameters of servo valves were determined using datasheet of MOOG flow control servo valves and then derived to second order transfer function. However, the transfer function must be validated using simulation. Generally, the models that develop from mathematical model are used for simulation study by using software (Anu Maria, 1997).

In this study, the transfer function and system model were based on experimental data. The experimental data of hydraulic servo system will analyze and simplified to get transfer function and thus develop the model for hydraulic servo system in MATLAB. The transfer function that simplified from experimental data must be validated to make sure that it is approximately described the dynamic behavior of a hydraulic shaker system. Other than that, the parameters in the system must consider such as the value of constant and gain for this system. They will also affect the system model. The transfer function can be validated by running a simulation of the model developed. Simulink had been used for simulation system model.

2.5 SIMULATION

Simulation is a tool to evaluate the performance of a system, existing or proposed under differences of configurations of interest. Simulink is software which is a graphical environment for dynamic system modeling, simulation and analysis interactively. The model in Simulink will represent as block diagrams for simulation. Simulation is used before an existing system or a new system is built to reduce the chances of failures and to meet the specifications of the system (Anu Maria, 1997). In Simulink environment, the complex system can be built to simulate the model. Simulation is running the system model in virtual to study the dynamic behavior of the system and thus, optimize the performance of the system. Besides that, simulation is for purposes to develop a control system for controlling performance of a hydraulic servo system.

The Simulink module library consists on sinks (output module group), sources (input module group), linear (linear link module group), nonlinear (non linear links module group) and also math (mathematical operation module group). These modules can make convert easily the system simulation into the simulation model (Junlan et al, 2011). The simulation model for hydraulic servo system will construct using experimental system. Load flow, pressure, velocity and other dynamics in the hydraulic system will include in the model of the system. However, in this study, the simulation required to determine the value of gain to compare the dynamic behavior of model and experimental data. Simulation test results with respect to changes in the model parameters (Dcehrit, 2009; Nitin, 2009).

In the past studied, J. Cheng et. al, was working out in modeling and simulation for the electro hydraulic servo system based on Simulink. They established mathematical modeling based on control theory for electro hydraulic position servo system, simulating using Simulink and applied M files and module mask function to simplify the system simulation process. Besides that, (H. K. Kim et. al, 2012) applied iterative control for modeling the hydraulic actuator. They had designed servo valve, the piston, the cylinder and the mounting part as linear and nonlinear system. They used iterative control algorithm in simulation the model. They work on the shaking table which large payload mounted on the actuator. The virtual system was simulated in Simulink.

The hydraulic servo system has a non-linear system that causes the system difficult to control. Simulation can optimize the dynamic performance by controlling the speed and position of the actuator of the hydraulic servo shaker. The simulation will show the dynamic behavior of a hydraulic servo system and thus can study them for developing the control system. The control system will help to control the performance of a hydraulic servo system and thus, optimize its performance.

2.6 CONTROL SYSTEM

The hydraulic servo system is a non-linear system and causes it difficult to control. Thus, it required control system to control and optimize the performance of this system. A control system is a system that is can manage and regulate the behavior of a system. The performance of the system improving by developing control system that makes the system following the desired command that had been sent to the system. The control system can be developed using apply open loop system and closed loop system during the experiment. Open loop system is collecting data by controlling input and not self-adjusting. Closed loop system is a self- adjusting system and not controlled by the input and the internal feedbacks are fixed. In other words, closed loop system gets feedback from a sensor and use it to correct the system performance. However, there may some disturbance or noise that will affect the experimental data, thus requires another controller that can improve the performance of the system.

Proportional, integral and differential is a PID controller, which is widely control application for the most control systems. The hydraulic servo system was applied PID controller in the previous studied. (J. Cheng et. al, 2011) had applied digital PID to getting ideal system dynamic performance. They developed and optimized dynamic performance by setting PID parameters for controlling the valve of the hydraulic servo system. Other than that, some studies had developed a control system which combines of PID algorithm and fuzzy control (J. Shao et. al, 2009). They improved the structure of fuzzy controller and bring out the fuzzy PID control to improve the control effect. For this project, the control system of PI, PD and PID will apply in a hydraulic servo system and comparing based on the performance of these controllers.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The driver circuit for hydraulic servo shaker built for experimenting setup. The driver will run the hydraulic system with control by programming command. The displacement sensor mounted to the shaker to give feedback on the position of the piston during running the shaker. Data acquisition will be used to collect and save the data from the shaker. From the experimental data, hydraulic servo system will model and simulate in MATLAB and Simulink. The data from the experiment of hydraulic servo system analyzed using MATLAB to develop mathematical equation that is transfer function of the system. The transfer function that had been obtained required validate by conducting simulation in Simulink. The transfer function validated by comparing the graph from simulation of the system model and the graph that plotted from that experimental data. MATLAB and Simulink will help to analyze the dynamic characteristic of the system based on graph obtained. The methodology of this research summarized in the Figure 3.1 below.

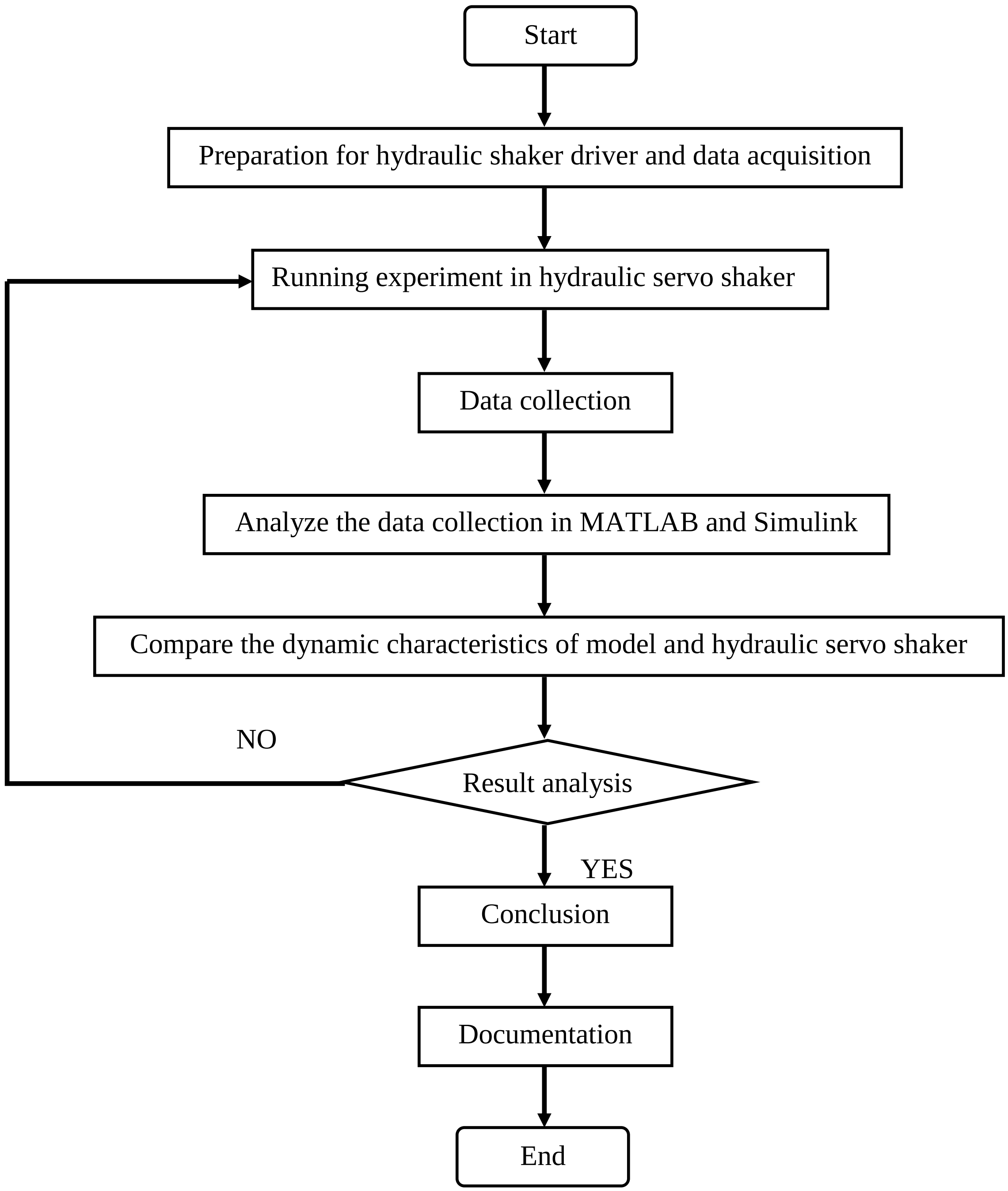

Figure 3.1 Summary of Research Methodology

3.2 FLOWCHART FOR THE EXPERIMENT

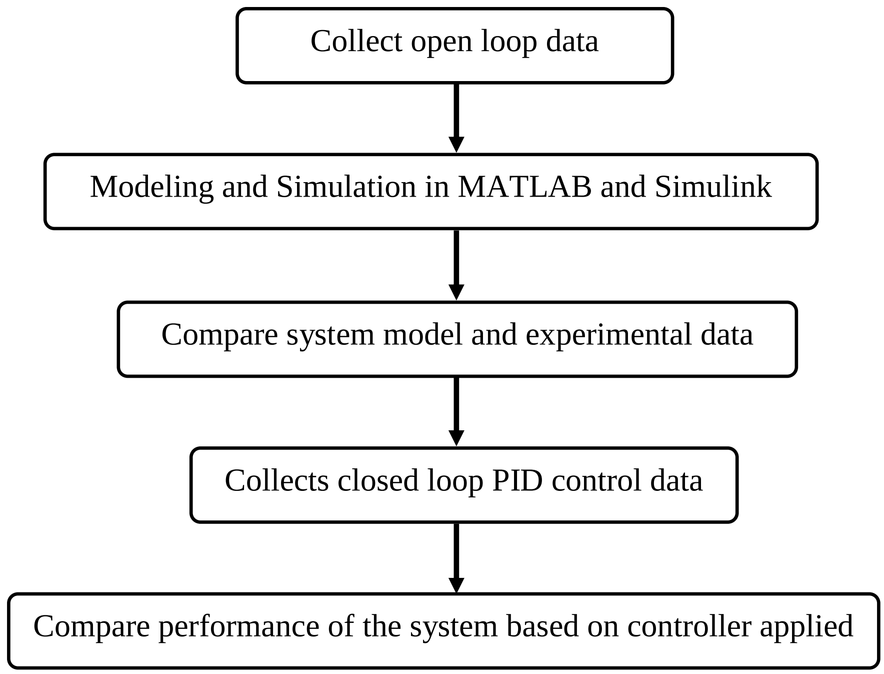

Figure 3.2: Flowchart for the Whole Experiment

Figure 3.2 shows the steps for the experiment that are done in this study. The hydraulic servo shaker was being conducted and collected the open loop data to develop transfer functions of the system model. System model developed in MATLAB and had simulated in Simulink. System model compared with experimental data to validate the transfer function of the system model. After that, experiment conducted again for collecting closed loop PID control data. The experiment was applied PI, PD and PID controller. The experimental data was analyzed the performance of the system based on the controller used.

3.3 HYDRAULIC SERVO SHAKER

Hydraulic servo shaker is an apparatus that used for shaking test or shaking structures by placing the specimen under test on the plate placed on an actuator. It has been used widely in modern industrial application due to it has the ability to apply large force and torque. The hydraulic servo system used pressuring fluid in the valve for moving the piston. In this study, hydraulic servo shaker applied for testing suspension system of the car.

Figure 3.3: Hydraulic Servo Shaker

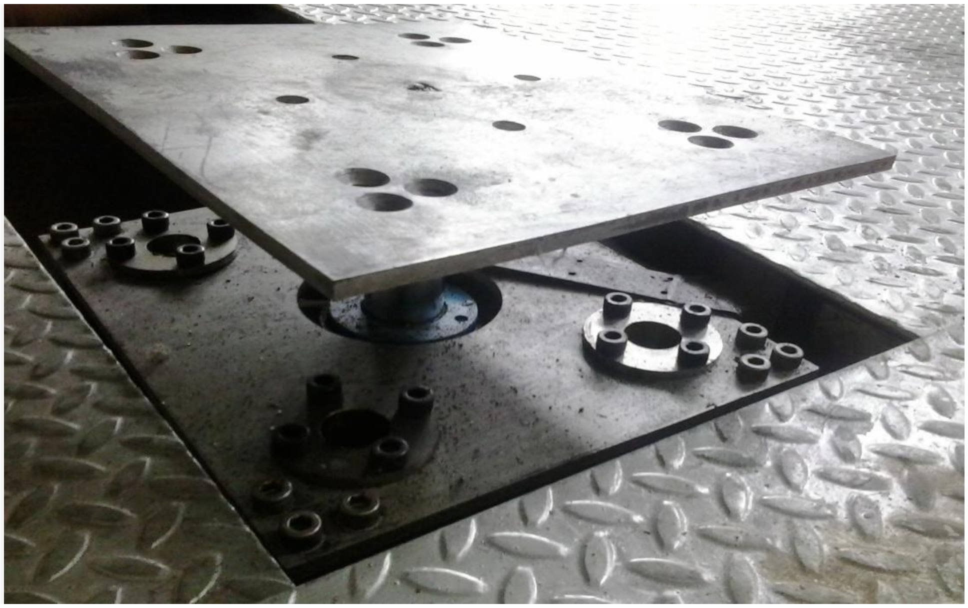

Figure 3.4: Piston of Hydraulic Servo Shaker

Hydraulic Servo Shaker required pressure for moving the piston of hydraulic system. Hydraulic Servo Shaker will control by using electrical signals that generates by a driver circuit of hydraulic. An electrical signal sent using programming command. Hydraulic power supply will supply hydraulic fluid flow in servo valve to drive the actuators to move in desired direction. This driver circuit can generate voltage from -10V to +10V. Figure 3.5 shows the hydraulic driver circuit.

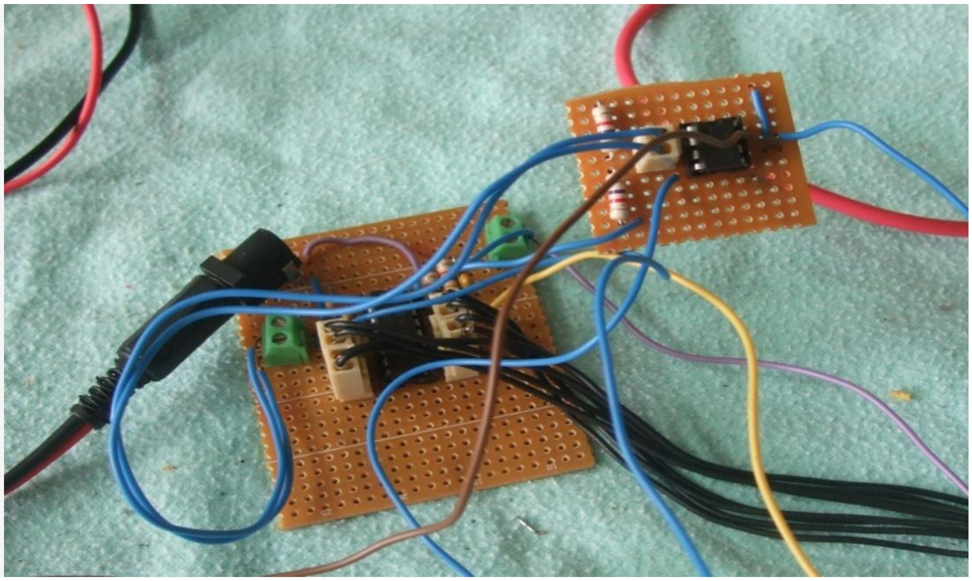

Figure 3.5: Hydraulic Driver Circuit

The experimental data from hydraulic servo system was collected by using the Sharp Analog Distance Sensor with series GP2D120. This displacement sensor mounted to the hydraulic servo shaker to give feedback on the position of the piston during conducting shaker. This short-range sharp analog distance sensor had a detection range between 4 cm to 30 cm. This shorter-range will gives higher resolution measurement and lower minimum detection distance. This sensor is suitable for detecting a close object. This sensor will indicate the distance by analog voltage. The displacement signals of the shaker derived from the sensor and transform of angular signal. However, this sensor is sensitive to light and gray color surface thus, needs to place white paper on the plate of the actuator so that it calibrate accurately. Besides that, the sensor mounted under actuator plate for reducing the light effect on calibration of the sensor.

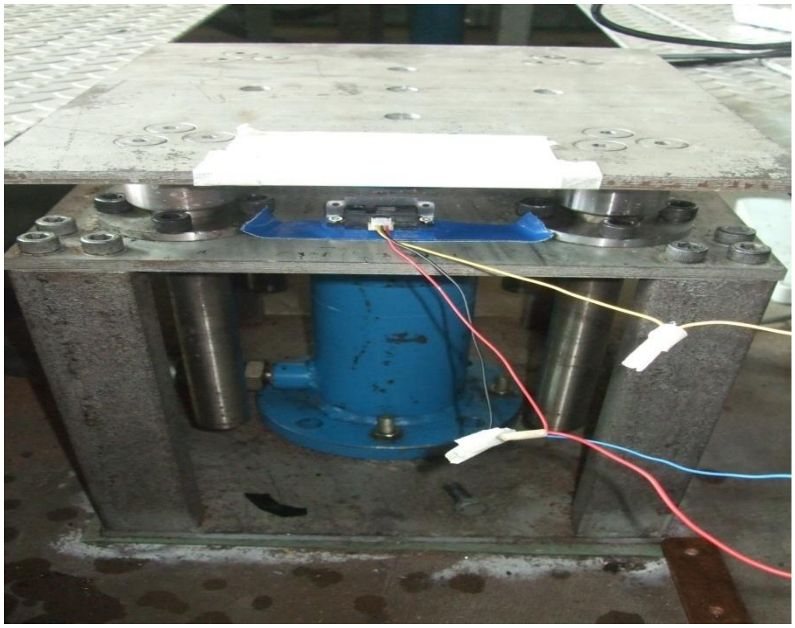

Figure 3.6: Mounted Displacement Sensor in Hydraulic Servo Shaker

3.4 DATA ACQUISITION

The signal from the sensor converted into digital data that processed in the computer by using data acquisition. Data acquisition is a process measuring electrical or physical phenomenon with a computer. The data acquisition system will consist of sensor, measurement hardware and programmable software. In this study, PCI 1712 Advantech Manager Data Acquisition used for collecting data from sensor to keep in the computer. PCI 1712 is a high- speed multifunction data acquisition card. The features of this data acquisition are having 6 single –ended or 8 differential analog inputs and have 12 bit analog to digital converter. Furthermore, the channel gain for each analog input channel can be programmable.

PCI 1712 Advantech Manager Data Acquisition requires wiring cable and wiring board for collecting data from sensor. The wiring cable for PCI 1712 is model PCL-10168 that would provide higher resistance to noise. To improve the quality of signal, the signal wires twisted to form twisted-pair cable for reducing crosstalk and noise from other signal sources. For wiring board for this data acquisition, it required ADAM 3968 wiring board with 68 pin wiring terminal module. This terminal module can easily connect to the Advantech computer cards for accessing individual pin connections. The output voltage wire from sensor needs to connect to the output channel of wiring board while ground from sensor needs to connect to output ground channel.

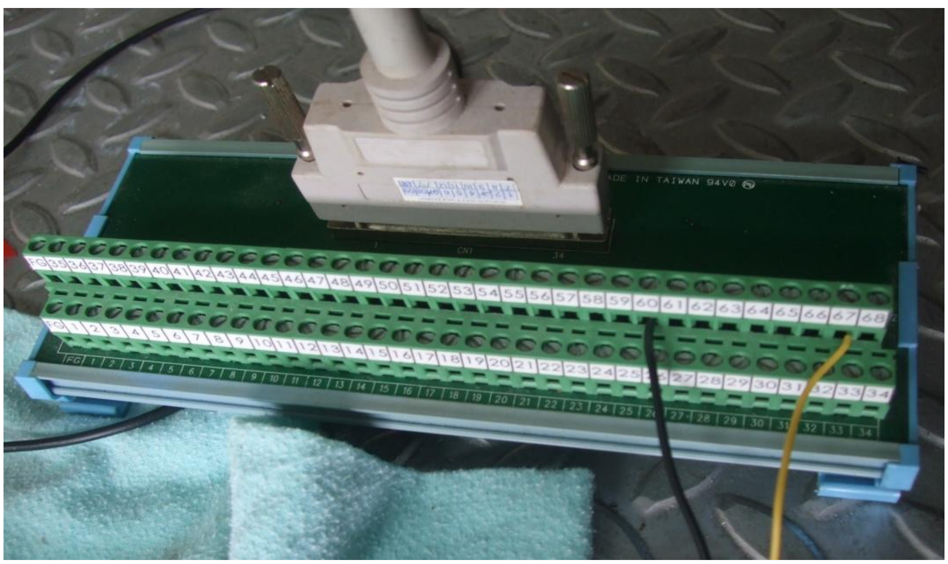

Figure 3.7: PCI 1712 Advantech Manager DAQ

3.5 MATLAB AND SIMULINK

The experimental data plotted and analyzed using MATLAB to obtain the transfer function of the system from modeling. The model that developed by using MATLAB then was simulated using Simulink. Modeling and simulating of the system model is for the purpose to analyze dynamic system and develop the control system. MATLAB provides state space for transfer function that represents the dynamic systems. The transfer function is a system time domain and frequency domain output or input representation that getting used Laplace Transform. The analysis model is to predict how the system will respond in both the time and frequency domains. Modeling is for purposed to find the transfer function of the system from experimental data. The model then simulated in Simulink. System model in MATLAB analyzed further in Simulink using simulation.

Simulink is very straightforward to represent and then simulate a mathematical model that represents a physical system. Simulink model is represented graphically in Simulink as block diagrams. Simulation of the system was conducted in Simulink by used of transfer function was found from modeling the experimental data of the hydraulic servo shaker. The graphical output from the system model compared with graph output from experimental data to validate the transfer function. After the transfer function validated, the system analyzed further to optimize the dynamic performance of the system by designing the controller for the system.

The hydraulic servo system is non-linear system and has problems with high nonlinearity, parameter variations and motion friction. Therefore, they need a controller that can work properly with the high nonlinearity phenomenon. The experiment of hydraulic servo shaker had done in two steps. Firstly, the experiment collected data for open loop systems for getting transfer function of this system. Then, closed loop system that is sensor had given feedback on desired position of the piston had applied in the same experiment. PI, PD and PID controller applied in the experiment and the performance of hydraulic shaker compared based on the uses of those controllers.

3.6 EXPERIMENTAL SETUP

3.6.1 Experimental Planning

To conduct the experiment, it was required to prepare the driver circuit of Hydraulic Servo Shaker for moving the actuator and a data acquisition card (DAQ) for collecting experimenting data. The experiment will be conducted for various speeds by applying a varying voltage. Besides that, the computer used also needs to install the software for data acquisition that is PCI 1712 Advantech Manager. This software required C program that will program the channel and gain used in PCI 1712 data acquisition and wiring board. The experiment had been conducted using the open loop system and a closed loop system. Figure 3.8 and figure 3.9 show the block diagram for an open loop system and closed loop system.

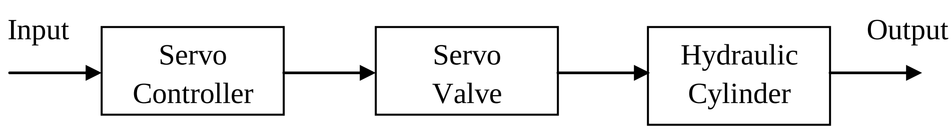

Figure 3.8: Block Diagram of Open Loop System

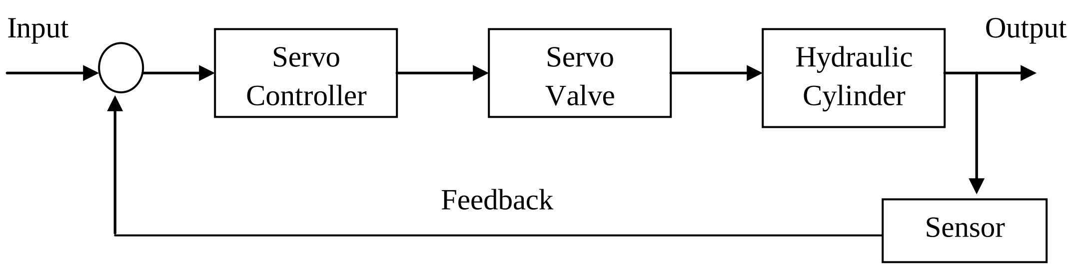

Figure 3.9: Block Diagram of Closed Loop System

In this study, MATLAB and Simulink will be used to model and simulate the hydraulic servo system. Based on modeling and simulation, the dynamic characteristic system can be studied. The hydraulic servo system is difficult to control due to non-linear system characteristics. By using modeling and simulating, the controller for this system can be designed to optimize the dynamic performance. There are two steps of experiments need to do modeling and optimize performance of the hydraulic servo shaker. Firstly, we applied open loop system of hydraulic shaker and collected the data. Open loop data analyzed to get the transfer function of this system. To validate the transfer function, the model simulated in Simulink and the graph output will compare with a graph of experimental data. Then, we had applied closed loop system for the purpose to design the controller for the hydraulic servo shaker. The controller will help to optimize the dynamic performance of hydraulic shaker.

3.6.2 Experimental Procedure

To design the experiments, the following steps implemented in the experimental design. Starting with setup the circuit driver of hydraulic shaker, it must work to move the piston of a hydraulic. Then, the sensor must be calibrated before mounting onto hydraulic shaker so that it will calibrate more accurate. For better accuracy during calibration of the sensor, the factors that will affect the calibration of the sensor need to identify so that it can avoid during collecting the data. After prepared driver circuit and the sensor mounted, data acquisitions need to set up. Experimental data collected by using data acquisition. In this experiment, we used PCI 1712 DAQ to receive the data from sensor and saved in the computer. The last step before running the experiment is preparing the program for collecting data. The programs need to set up the channel pin use for DAQ cards and the analog output ground of the driver circuit of hydraulic Shaker.

The experiment was conducted with varied voltage from 5V to 10V was supplied to hydraulic shaker. This is for the purposed to collect data for various speeds of hydraulic system. To supply various voltages, the address of output voltage in parallel port needs to identify. For supplying output voltage to hydraulic shaker, the address programmed to give command. The address would be changed in the programming following desired supplied voltage to the system before conducting the experiment.

Table 3.1: Address of Output Voltage

Output Voltage (V)	**Address**
5	67
6	115
7	219
8	231
9	207
10	255

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will present all the experimental data and results of analysis from the experiment of the hydraulic servo shaker. All of them will present in the form of tables, graphs and figures. The experimental data collected and analyzed to obtain the transfer function of a hydraulic servo system. The transfer function obtained by modeling the system using experimental data. The further explanation of modeling the system will be in the next section. Then, the transfer function that had got must be validated by comparing the graph output of the system model and graph that had been plotting by using experimental data.

The system model and experimental data was being compared by running the simulation using Simulink in MATLAB. All modeling and simulation were being used MATLAB and Simulink to analyze the data. Lastly, the experiment was being done using a closed loop system and applied PID controller to optimize the performance of the system. In addition, the performance of the hydraulic servo system compared based on the uses of PI, PD and PID controller.

4.2 OPEN LOOP RESULT

4.2.1 Speed Result

The experimental data that collected from the hydraulic servo shaker conducted using the open loop system. It aims to analyze characteristic of a hydraulic servo system and find the transfer function. This experiment was carried out using a variety of speeds by programmed to supply various input voltage to the system. Figure 4.1 shown the differences speed in different input voltage. The graph of position versus time had shown that the time taken for every speed that applied to the system to reach the maximum distance.

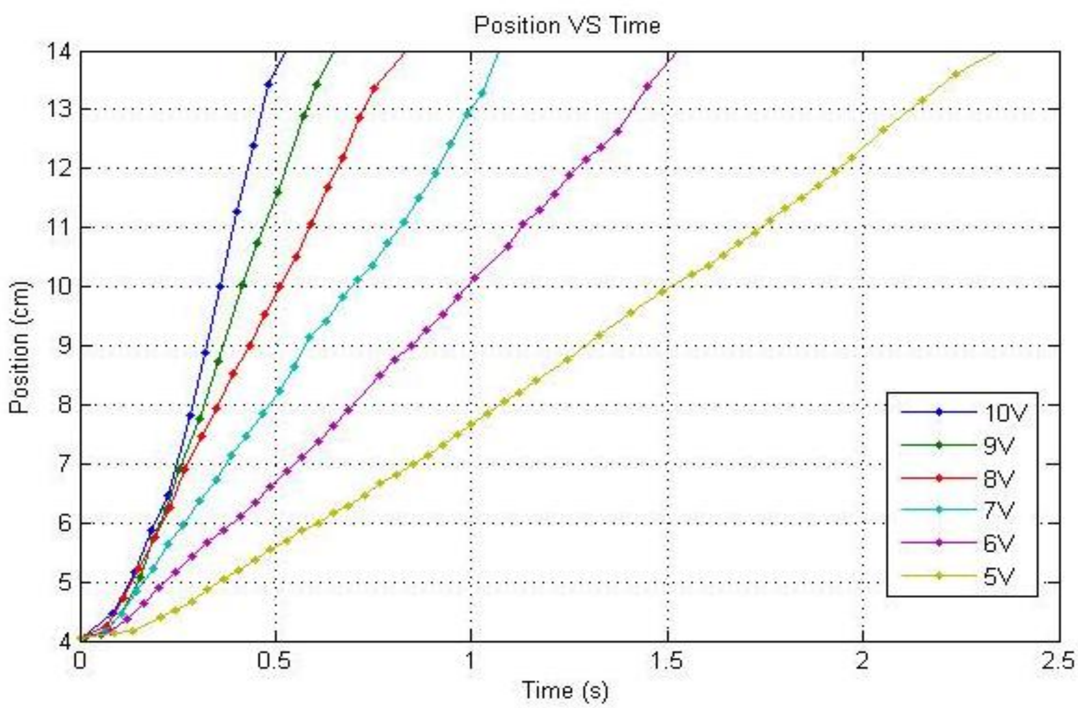

Figure 4.1: Comparison of Speeds with Their Input Voltage

From the Figure 4.1, it showed that for input of 5V, it takes about 2.3 seconds to reach maximum distance while for input voltage of 10V, it only required 0.52 seconds to reach maximum distance that is 140 millimeters. It can be seen that the speed increase proportional to the input voltage. Thus, from the position versus time graph, the speed of hydraulic motion calculated by finding the gradient of the graph for every input voltage. Gradient calculated by using formula below.

$$\text{Gradient} = \frac{y_2 - y_1}{x_2 - x_1}$$

Below is the table that shows the result of input voltage with their speed respectively.

Table 4.1: Results of Input Voltage with their Speed

Input Voltage (V)	Speed (mm/s)
5	47.01
6	67.38
7	95.70
8	134.56
9	189.71
10	273.76

From Table 4.1, the data show the speed of the system had increased with increasing the input voltage supplied to the system.

The speed then used in modeling the system to find the transfer function of a hydraulic servo system. Value of speed used to find the value of gain in the system model that known as K.

4.2.2 Modeling

4.2.2.1 Graph K versus Voltage

K is the value of gain that implemented in the system model. The value of K can be determined by dividing the value of speed with their respectively input voltage. However, since the noise effect may affect the reading of the sensor, it was required to obtain the average of value K. The average taken by plotting the graph of K versus Voltage and then obtain the equation of the graph. The equation will use to find the value of gain and constant in the system model. Figure 4.2 showed the graph of K versus Voltage.

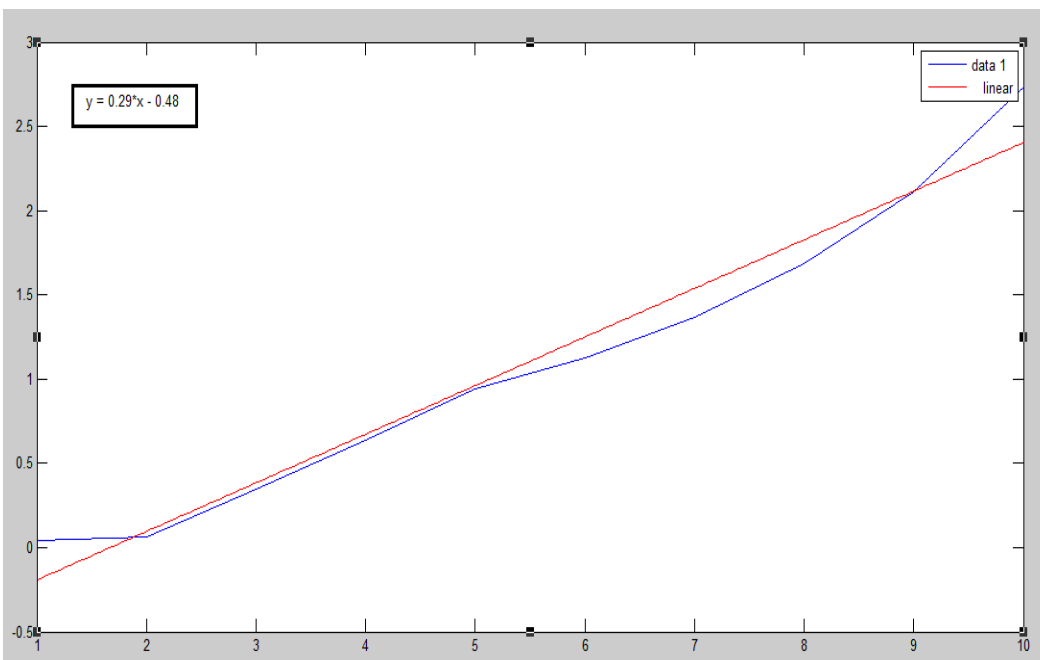

Figure 4.2: Graph of K versus Voltage

4.2.3 System Model

The important part of the system model is transfer function. Transfer function will describe the dynamic characteristics of the system. In this project, the first-order transfer functions for controlling speed used. The basic formula for first-order transfer function is

$$\frac{Speed}{Voltage} = \mathrm{K}\left(\frac{a}{s+a}\right)$$

Since the value of gain, which is K, and value of constant had got above, the transfer function of this system founded. However, the transfer function needs to be validates to confirm it is describing the characteristics of hydraulic servo system. The transfer function validated by running the simulation on the system model. Figure 4.3 shows the system model that built.

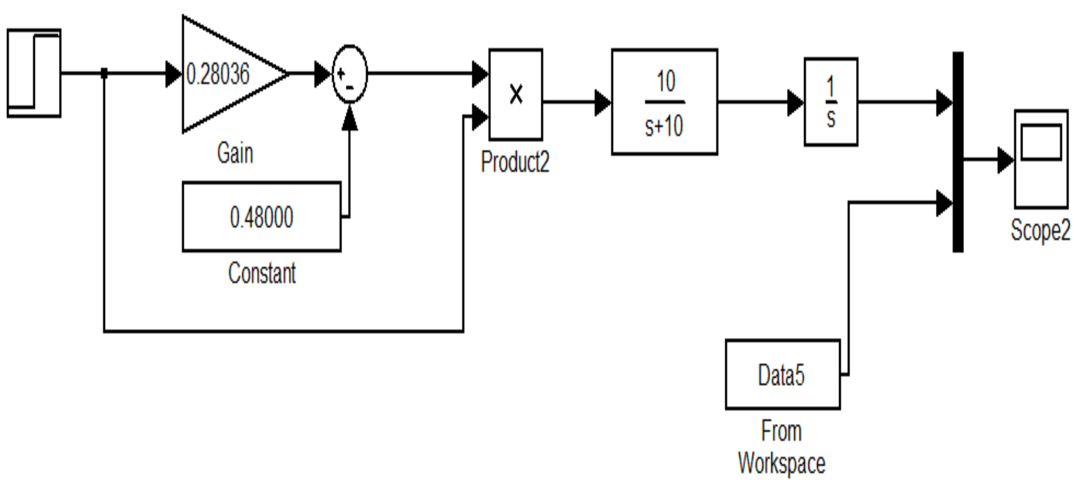

Figure 4.3: System Model of Hydraulic Servo System

4.2.4 Simulation

The transfer function validated by comparing the output graph of the system model and from experimental data. After running the simulation, the value of gain needs to change to make system model following the experimental data output graph. The graph that had been compared system model and experimental data showed below.

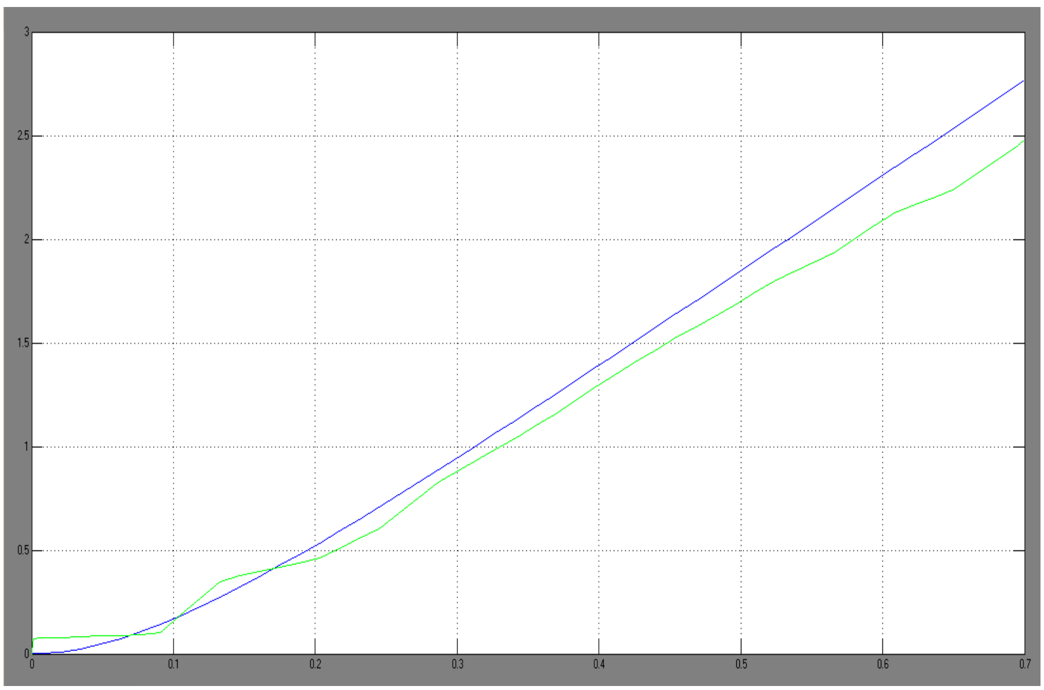

Figure 4.4: Simulation of System Model and Experimental data for 5V

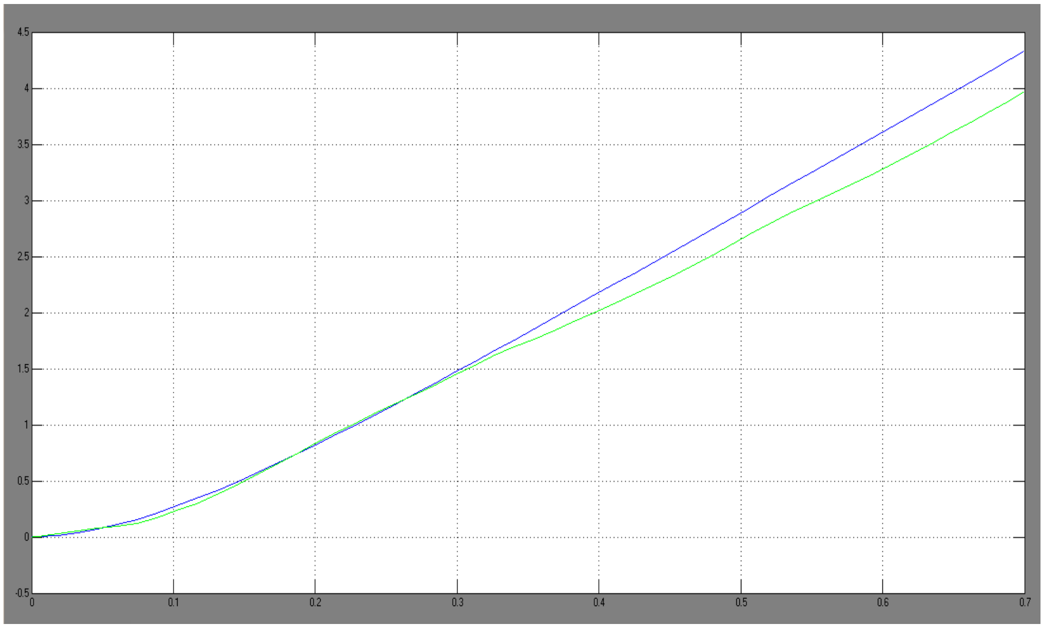

Figure 4.5: Simulation of System Model and Experimental data for 6V

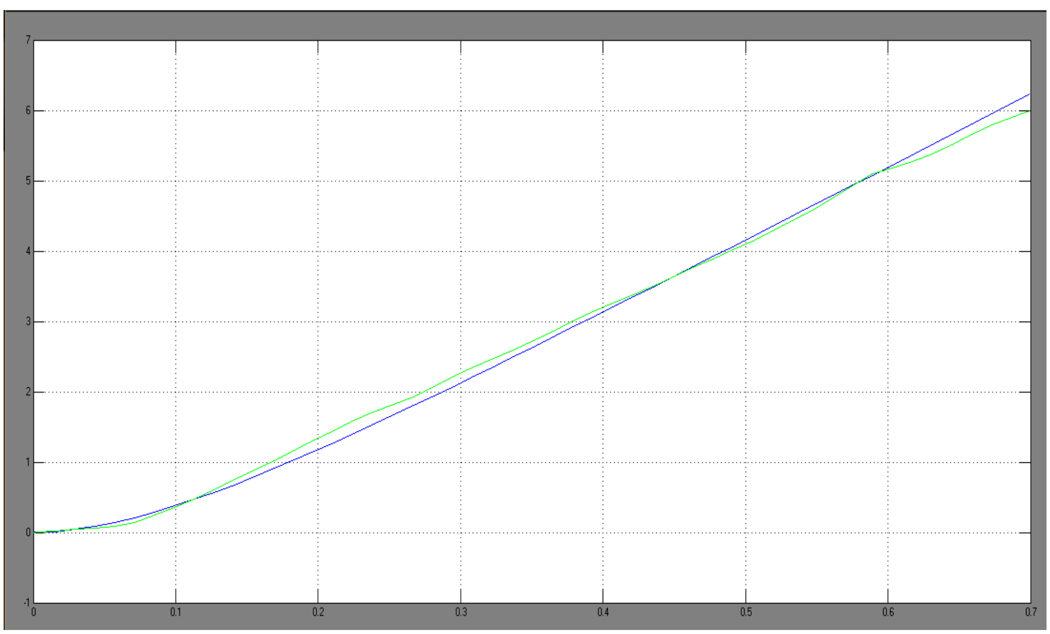

Figure 4.6: Simulation of System Model and Experimental data for 7V

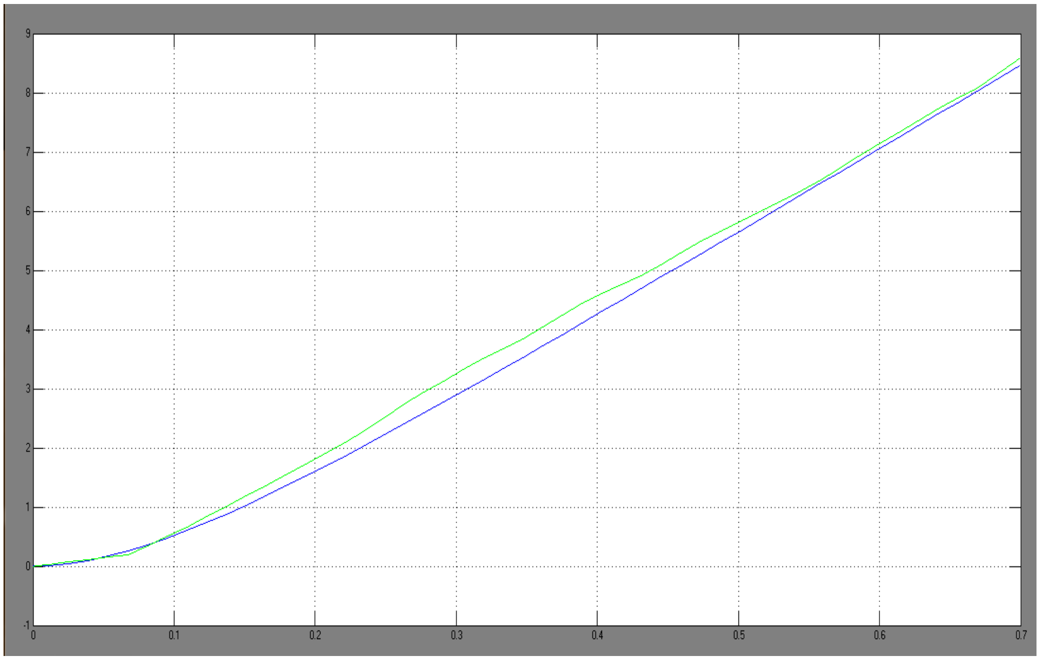

Figure 4.7: Simulation of System Model and Experimental data for 8V

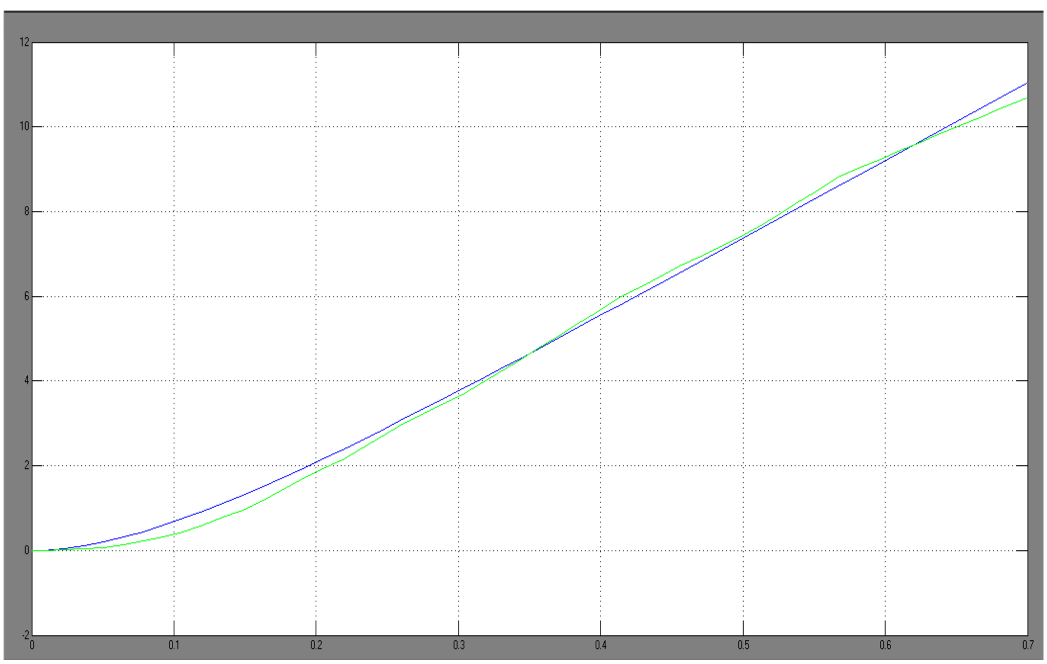

Figure 4.8: Simulation of System Model and Experimental data for 9V

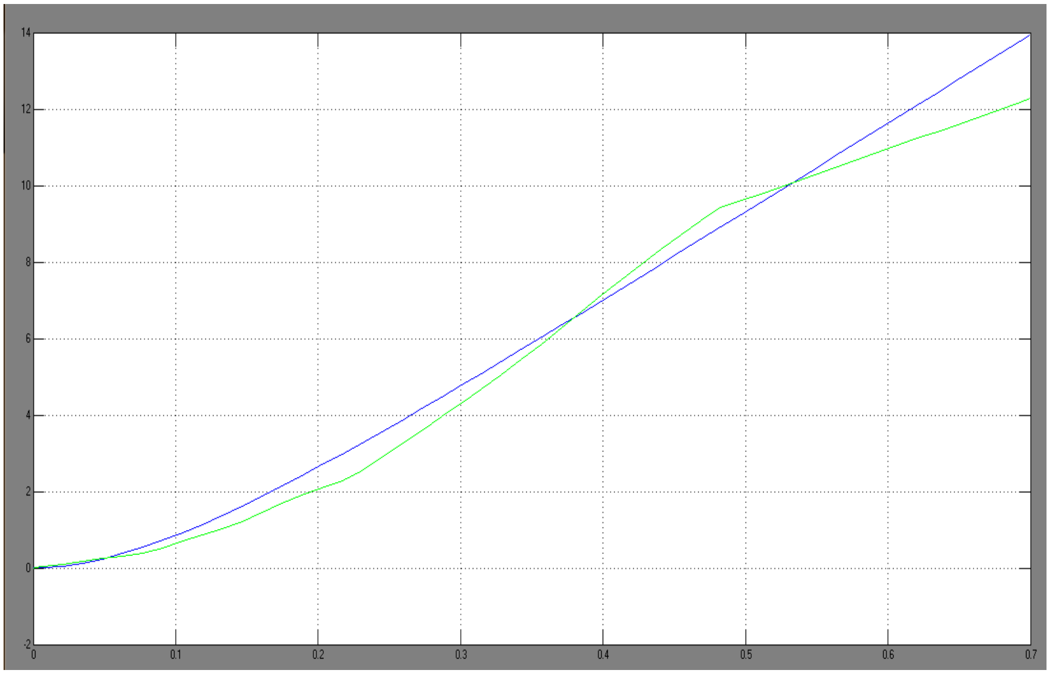

Figure 4.9: Simulation of System Model and Experimental data for 10V

Based on the figures above, there was showed that the graph curve for system model and experimental data was approximate each other. Thus, it concluded that the transfer function and the system model above are acceptable for this hydraulic servo system.

4.3 CLOSED LOOP RESULT

4.3.1 Result of PI, PD, and PID Controller

Closed loop control is a response is measured and feedbacks to the control system so as to refine or modify a drive signal in order to bring the response closer to the references or desired positions. In this project, the closed loop control experiment was conducted by setup desired positions are 30 mm, 50 mm and 70 mm. Besides that, during conducting the experiment, the PID controller applied. The experiment conducted by used of PI, PD and PID controller for every desired position of the piston. The result of those experiments showed below.

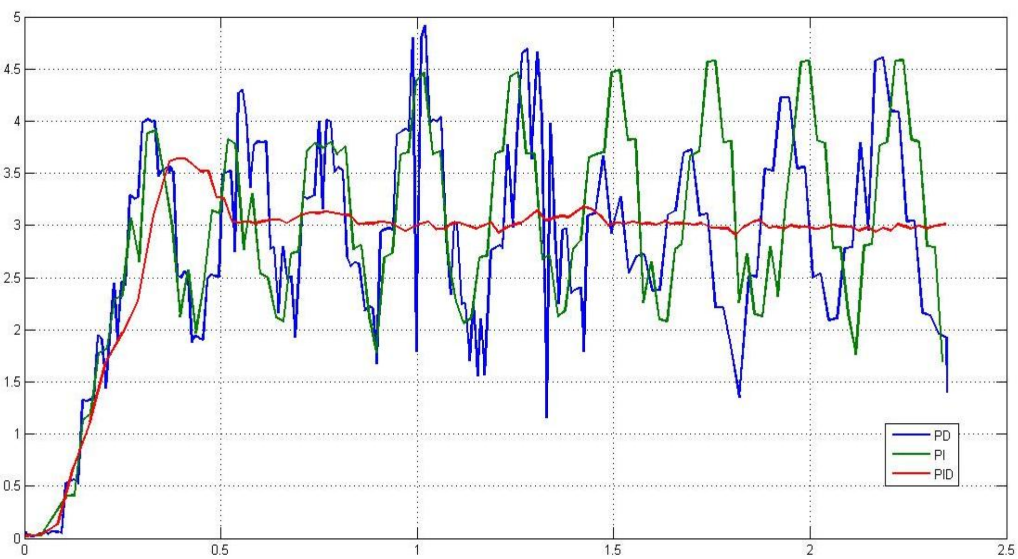

Figure 4.10: Result of Closed Loop Control for Desired Position is 30 mm

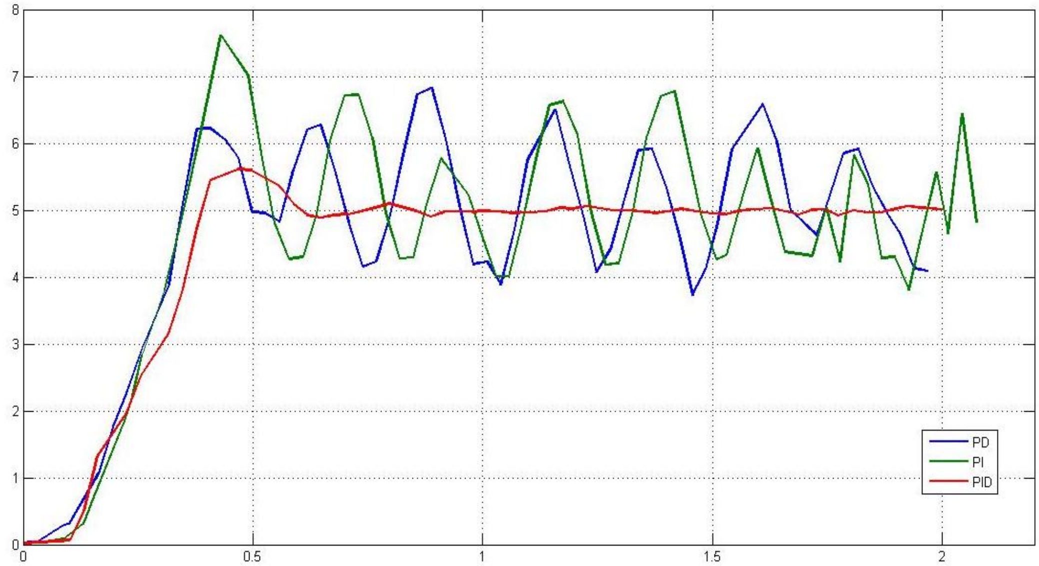

Figure 4.11: Result of Closed Loop Control for Desired Position is 50 mm

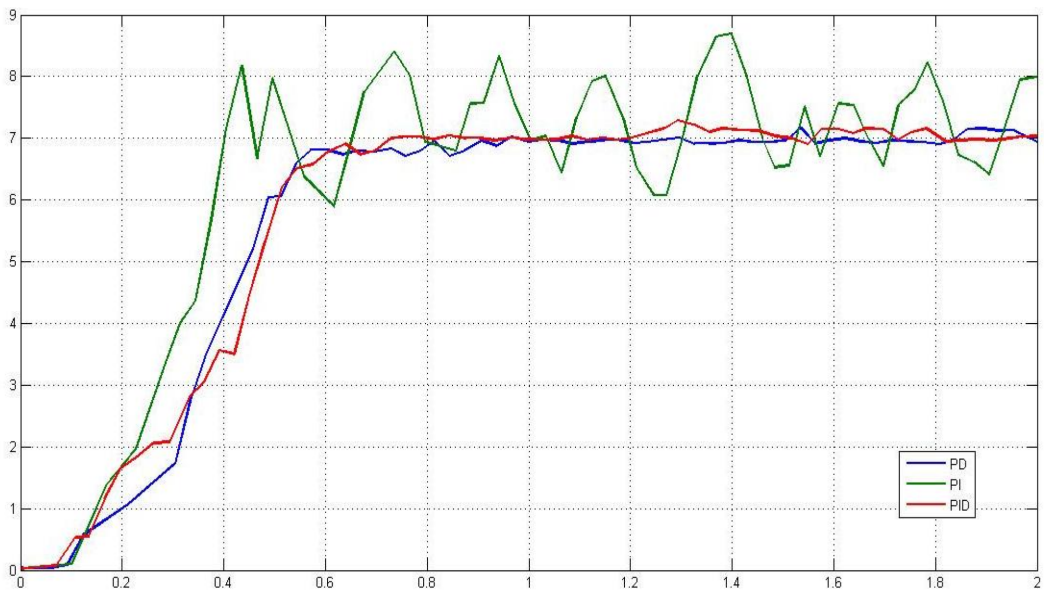

Figure 4.12: Result of Closed Loop Control for Desired Position is 70 mm

PID controller is referring to proportional, integral and derivative controller that widely used in controlling for closed loop system. The PID controller controls a system by calculating the error, which is the difference between process variable and desired set point. Proportional, integral and derivative gains in PID controller have their own function to optimizing the system. Proportional is for calculating the error and make a system to approach the desired of a system. In a hydraulic servo shaker, it will calculate the error of system by calculating the differences of the desired distance and process variable and then make manipulated variable moving the piston to the desired position. Integral gain was functioned as increasing the speed of the system and eliminates the steady state error while derivative gain would help to stabilize the system.

From the experimental result plotted above had shown the performance of the system for every desired position that had been set up with three types of controller. PI controller was increasing the speed of piston motion to achieve desired positions, however, it have highest percent overshoot compare to PD and PID controller. This is due to integral gain accumulated the errors and cause the system overshoot. This makes the system not stable. Furthermore, the value of proportional gain also would affect their stabilization of a system. If value proportional gain, Kp too high, the system becomes unstable but if Kp too low, the system will become less responsive and less control action. This can be seen from the experiment of desired position of 30 mm and 50 mm, the value of Kp is too high and cause the system unstable. Value proportional gain, Kp used for 30 mm and 50 mm is 1.575 while for 70 mm is 0.9575. Value integral gain, Ki and derivative gain for all experiments is 0.001 and 0.03 respectively.

PD controller had less overshoot percent compared to the PI controller due to the controller not have integral gain which functioned to eliminate the steady state error and increasing the speed of a system. PD controller can help to stabilize the system due to derivative gain used for stabilizing the system. However, PD controller may cause the system not achieved desired position. The experiment for desired position is 70 mm, the uses of the PD controller causes the system not achieved desired position even though the system stabilized. Thus, it concluded that PD controller is not an efficient controller for optimizing the performance of the hydraulic servo system.

For all the results of experiments that conducted above, there showed that PID controller has optimized the performance of the hydraulic servo shaker. Even though for parameters of 30 mm and 50 mm, it still had overshoot at initially but then the system became stabilized. For parameters of 70mm, PID controller performed well as the percent overshoot is too small and the system stabilized. PID controller becomes a better controller because it had a proportional gain that approach the system to desired position, has integral gain which can increase the speed of the system and eliminate steady state error and has derivative gain which can stabilize the system. The combination of those gains would help to control and thus optimize the performance of the system. The performance of the system analyzed further in the next section.

4.3.2 Comparison the Performance of the System

From the graph plotted above, the performance of a system based on the controller applied was calculated. The performance of the system calculated based on percent overshoot, peak time and rise time. Percent overshoot is the amount overshoot of the curve goes above the final value in percentage while peak time is the time at which peak occurs. Rise time is referring to the time taken for the output to rise from 0.1 of final value to 0.9 of the final value. The performance of the system can be considered as good performance as it has a small value of percent overshoot, peak time and rise time and must also stabilize.

Table 4.2: Analysis the Performance of System for Desired Position of 30 mm

Controller	%OS	Peak Time, Tp (s)	Rise Time, Tr (s)
PD	30.33	0.3139	0.1732
PI	33.37	0.3911	0.2390
PID	21.40	0.3886	0.2249

Table 4.3: Analysis the Performance of System for Desired Position of 50 mm

Controller	%OS	Peak Time, Tp (s)	Rise Time, Tr (s)
PD	24.26	0.3780	0.2291
PI	52.32	0.4298	0.3282
PID	12.28	0.4676	0.2354

Table 4.4: Analysis the Performance of System for Desired Position of 70 mm

Controller	%OS	Peak Time, Tp (s)	Rise Time, Tr (s)
PD	**-**	0.5707	0.4028
PI	16.91	0.4357	0.2699
PID	0.3286	0.6834	0.4541

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter will summarize for the whole project and gives some recommendation for the future work to improve this research. The conclusion and recommendations based on results and analysis that had found in this project. In addition, some suggestions to faculty due to the process of ordering and uses of laboratory for the final year project's study are needed to upgrade.

5.2 CONCLUSION

As a conclusion, the objective of this project achieved. This project is to model and simulate characteristics of hydraulic servo system and find the transfer function of the hydraulic servo system. In addition, the closed loop system with used PID controller applied and compared between PI, PD and PID controller.

Based on the result and analysis in the previous chapter, the following conclusion can be as follows:

1. The experiment conducted by using open loop and closed system to find the transfer function of the system and develop the controller for the system.
2. The transfer function of the system founded using first order transfer function system, which uses to control speed.
3. Modeling and simulation used to compare the characteristics of the system model and experimental data to validate the transfer function.
4. PID controller had given better controller for optimizing the system compared with PI and PD controller.
5. Sensitivity of the sensor needs to concern during conducting experiment due it will affect the reading of the sensor thus affect experimental results.

5.3 RECOMMENDATION

From the results that obtained from this study in the previous chapter, the following recommended could be working in the future:

1. The experimental data is not consistent and not really accurate due to noise effects from the sensor. This may affect the calibration of the sensor. Thus, in the future the sensor may change to the better displacement sensor that had less effect of noise during calibration.
2. The sensitivity of the sensor during calibration is important so that to get accurate experimental data. The sharp analog sensor is sensitive to light and gray surface. So, in the future, make sure the light is not too bright and use white surface to measure the distance by using this sensor.
3. Based on the result, PID controller better compared to PI and PD controller. Thus, PID controller used to control the system for optimizing the performance of the system.
4. Apply Ziegler – Nichols method in the future to tune PID controller to get the right value of the gains. This can improve the performance of the system more accurate.

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