Position Control System of Hydraulic Cylinder Based on Microcontroller

Asst. Lect. Munaf F. Bader
Mechanical Engineering Department, College of Engineering
Al-Mustansiriya University, Baghdad, Iraq

Abstract

Recently, the industrial applications using an electro-hydraulic system have been widely used. Since these are necessary and more ambitious specifications with respect to positioning accuracy, rapid motion and for generating large forces. Position control system is one of the applications in the area of the electro-hydraulic systems.

In this work, a single ended hydraulic cylinder with limit position sensor was employed. It was proposed to develop a position control system that incorporates features of a microcontroller interfacing with position sensors and detecting the position of the hydraulic cylinder rod.

Microcontrollers are ideal for embedded control applications since a self - contained control system may be constructed with just a few components. Developing such a system required to build a software part running on the microcontroller as well as a hardware part consisting of mechanical and electronic components. An electro-hydraulic system based on the proportional valve technology was employed. The heart of this system is an electrically adjustable proportional directional control valve linked to the embedded controller MCS51 via Proportional, Integral and Derivative (PID) controller .The simulation for the system was carried out by Simulink/Matlab model and the results show that the controller of the system can be easily tuned by software and adjusted to meet the requirements for the position control of the hydraulic shafts. Very high accuracy was achieved where error could be due to backlash of the hydraulic shaft and the resolution of converting analogue signals to binary.

الخلاصـــــــة

في ألآونة الأخيرة، أصبحت التطبيقات ألصناعية ألتي تستخدم ألأنظمة ألكهروهيدروليكية ضرورية وملائمة من ناحية دقة الإستجابة، سرعة ألأداء والحصول على قوة كبيرة. إن نظام السيطرة على طول الشوط للأسطوانة الهيدروليكية هو أحد مجالات ألتطبيق للأنظمة ألكهروهيدروليكية.

في هذا البحث، تكون الأسطوانة الهيدروليكية ذات نهاية واحدة ولمعالجة مشكلة عدم السيطرة على طول الشوط للمكبس الهيدروليكي تطلب الأمر تطوير نظام توقيف ذاتي مدمج مع ميزات المسيطر الدقيق وبوجود متحسسات توقف التي تتحسس طول الشوط للمكبس.

يعتبر المسيطر الدقيق مثالي للتطبيقات المختزلة نظراً لإمكانية بناء نظام سيطرة وبعدد قليل من المكونات. إن تطوير مثل هكذا نظام يحتاج إلى برنامج يدار من قبل المسيطر الدقيق إضافة إلى بناء منظومة كهروميكانيكية. لتحسين نظام السيطرة على توقف المكبس الهيدروليكي، تم إستخدام نظام هيدروليكي مستند على أساس تقنية ألصمامات التناسبية حيث أن الجزء الرئيسي في هذا النظام هو الصمام التناسبي الإتجاهي المسيطر عليه كهربائيا والمربوط مع المعالج الدقيقMCS51 عن طريق مسيطر من نوع PID ولمحاكاة المنظومة تم إستخدام برنامج MATLAB/SIMULINKلغرض الحصول على النتائج التي أظهرت إن هذا المسيطر يمكن تعييره وتضبيطه باستخدام هذا البرنامج والإلتقاء مع متطلبات السيطرة على موقع حركة المكبس الهيدروليكي وإمكانية تحقيق دقة عالية مع الأخذ بنظر الإعتبار إن الخطأ قد يحدث نتيجة لحصول Backlash في المكبس الهيدروليكي ومدى الدقة الموجودة عندما يتم تحويل الإشارة ذات النوع الكمي إلى نوع رقمي في دائرة التحويل الرقمي.

1. Introduction

Electro-hydraulic actuators are widely used in industrial applications. It can generate very high forces, exhibit rapid responses and have a high power to weight ratio compared with their electrical counterparts [1]. Many industrial applications in both military and civilian fields such as drilling platforms, plastic injection machines, cranes and fire vehicles need position control system. The accuracy of position system determines the kind of hydraulic module, which is used, and according to the required accuracy the hydraulic control valves can be selected.

The general classification of the hydraulic valves may be divided into conventional control valves and proportional control valves. The conventional models become inappropriate and have limited scope if one requires a precise and fast performance [2].

So for, fast response, high accuracy, an automatic position control module employing an electro-hydraulic subsystem depending on hydraulic valve technology and linked to the embedded controller is one of the best solutions. The basic part of this technology is the proportional directional control valves, with its solenoids, provide the ideal interface for electronic controls [3]. The proportional valve controls the direction of movement and the speed of the hydraulic cylinders the output hydraulic flow from it is proportional to the electrical input signal to the valve solenoid [4].

Microcontroller is an entire computer manufactured on a single chip. The I/O and memory subsystems contained in microcontroller specializes the device so that it can be interfaced with hardware and control functions of the applications. Due to the low cost and ease of integration within an application microcontrollers are used whenever possible to reduce the chip count of a piece of electronic components [5].

The second section explains the design procedures of the position control system in addition to the description of the platform structure and the electro-hydraulic subsystem. A detailed description of the experimental work of the position control system is presented in the third section, besides that the simulation of the electro-hydraulic system is presented in the fourth section followed by the conclusions.

2. Position Control System

The position control system may be subdivided into controller module, electro-hydraulic subsystem and position sensors, as shown in **Fig.(1)**. Position limit switch, which are fixed on the platform body, detect the inclination of the piston of the hydraulic cylinder and send a voltage signal to the interfacing circuit. The controller module of the position control system uses a closed loop control of the spool position of the proportional directional control valve based upon position feedback of the hydraulic cylinder piston.

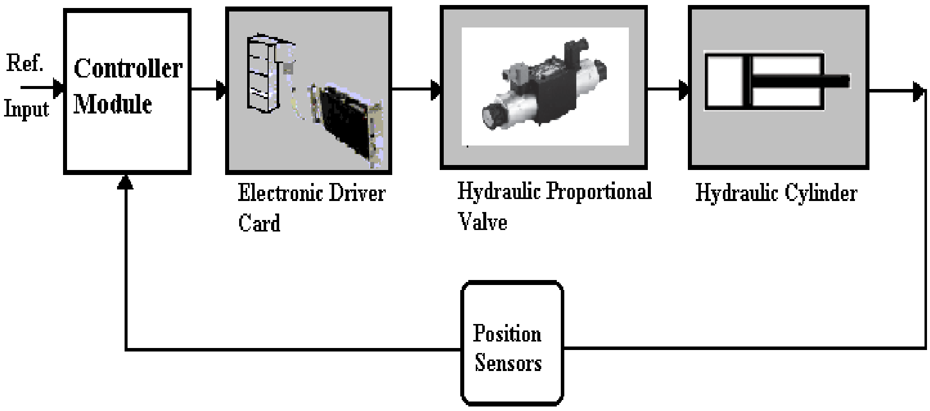


Figure (1) The proposed position control module

The varying voltages, which are applied to the solenoid of the proportional valve, change the flow of the hydraulic fluid that passes to the hydraulic cylinder. This will cause a change in the rod stroke of the hydraulic cylinder and consequently the position of the hydraulic cylinder shafts will be affected. Hence the controller detects the error between the set point and the measurement of the hydraulic shaft variable position.

Embedded system often requires real- time operation and multitasking capabilities. Real-time operation refers to the fact that the embedded controller must be able to receive and process the signals from its environment. Multitasking is the capability of performing many functions in a simultaneous or quasi-simultaneous manner [5].

To investigate this approach the following subsystems have been carried out:

1. Designing a controller module, which is based on a microcontroller system and an interfacing circuit connected with the microcontroller.
2. Developing a measurement module for the position sensors, which are primarily used to sense the stroke of the piston of the hydraulic cylinder.
3. An electro-hydraulic subsystem works with proportional directional control valve. The driver circuit for this valve consists of an electronic amplifier card, specifically designed for this valve.

4. Hydraulic cylinder fixed on the frame as shown in **Fig.(2)** to actuate the load, left and right, until the required position is achieved.

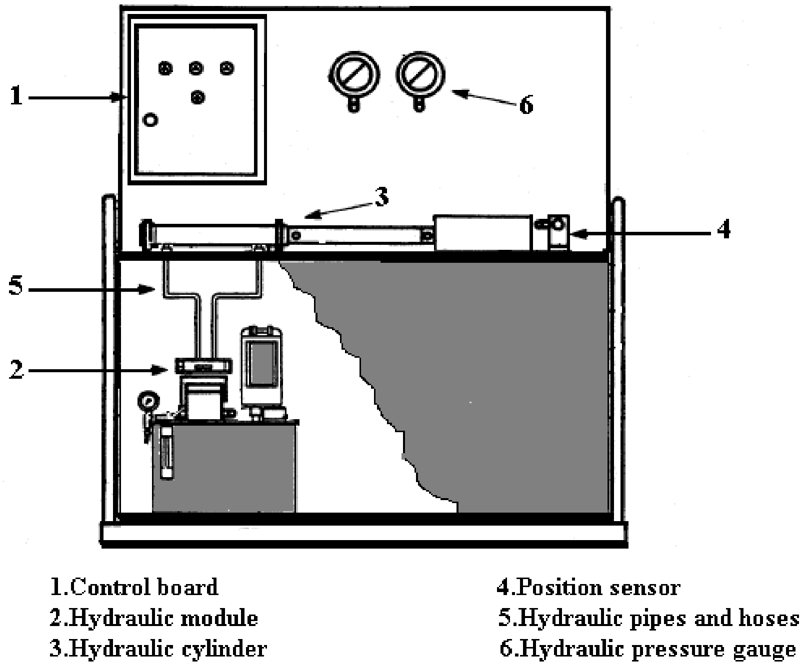


Figure (2) The position control system

3. Design of the Position Control System

The electro-hydraulic module of the position control system contains hydraulic cylinder and four ways, two electrical solenoid hydraulic proportional valves with their electronic cards representing the linking element between the controller module and solenoids of the valve. Each valve controls the flow and direction of the hydraulic fluid that passes through it towards the hydraulic cylinder leading to move the cylinder left and right with acceptable speed.

The employed hydraulic system as shown in **Fig.(3)** works with proportional valve technology, and the general items in this hydraulic subsystem are:

1. The power unit.
2. The hydraulic control unit.
3. Hydraulic cylinder.
4. Accessories.
5. Pipes and hoses.

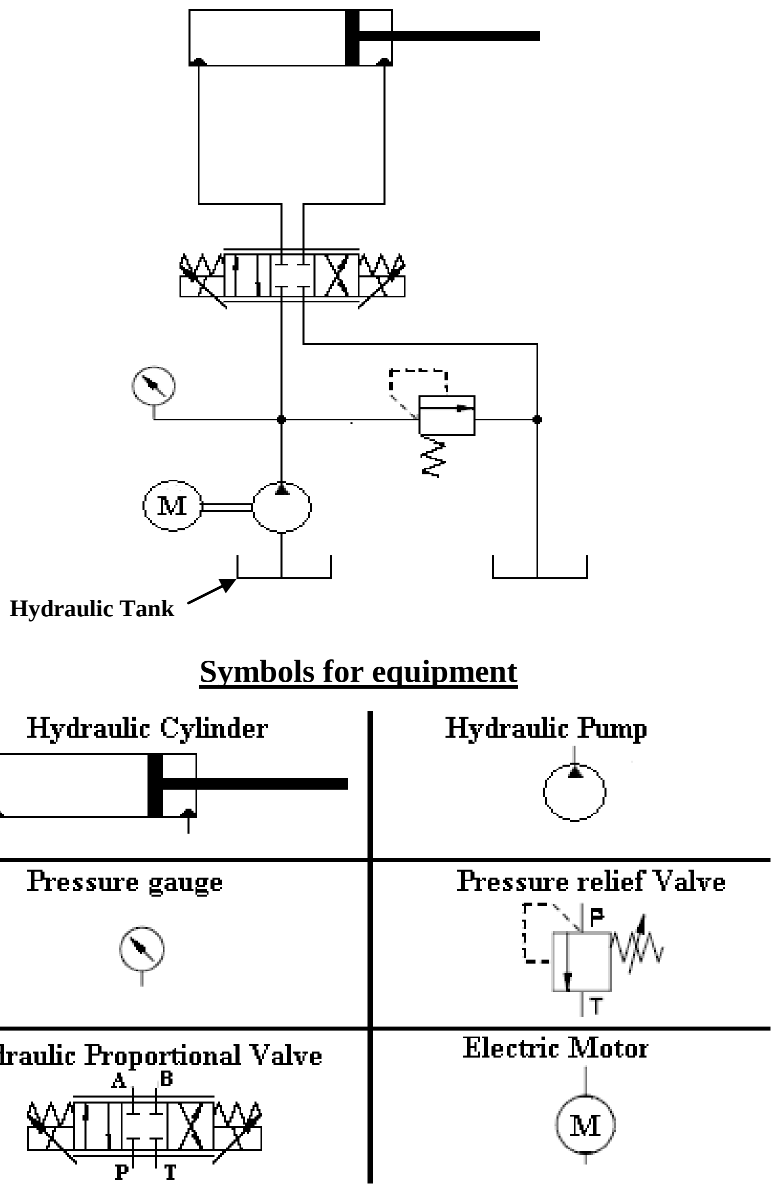


Figure (3) The diagram of hydraulic subsystem and hydraulic actuators

The hydraulic control unit consists of proportional directional control valves and their associated electronic amplifier card. Hydraulic cylinder of (50 mm) bore diameter, (28 mm) rod diameter and (250 mm) stroke is used to actuate the load left and right. The power unit of the hydraulic system consists of hydraulic pump, non-return valves, filter, and hydraulic tank. According to the signal coming from the electrical card, the control spool of this valve is shifted either to the right or to the left depending on the polarity of incoming voltage signal positive or negative, the stroke of the spool is therefore proportional to the electrical signal and it is used to control opening and closing function [6] as shown in **Fig.(4)**.

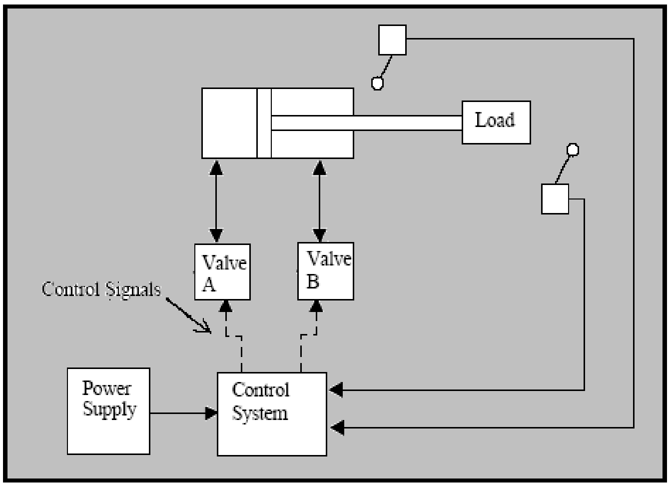


Figure (4) The hydraulic actuators employed in position control system

The voltage signals of the position sensors, which are received by the microcontroller, are proportional to the position of the hydraulic cylinder shaft and accordingly signals are generated and applied to a driver circuit that controls the hydraulic valve. As the signal increases the stroke will increase and the flow of hydraulic oil will increase causing greater volumetric flow [3]. The basic components of the valve are shown in **Fig.(5)**.

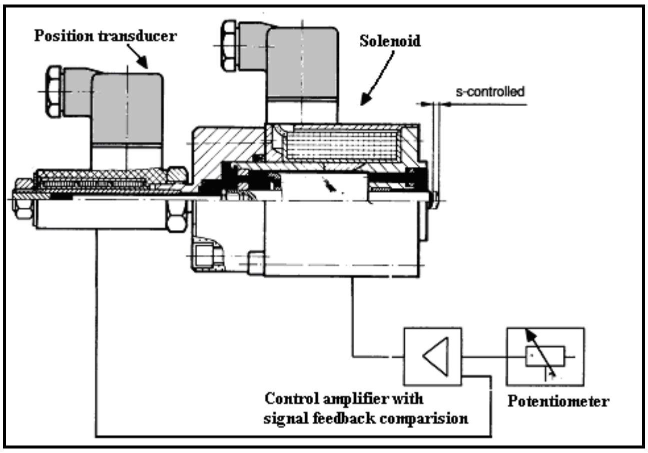


Figure (5) The stroke-controlled proportional solenoid [1]

The embedded controller module that was employed and prototyped position control system consists of the microcontroller MC51 besides interfacing circuits (ADC and DAC) as shown in **Fig.(6)**. The MC51 reads the voltage values and compares them with the set point of initial position that is stored in it.

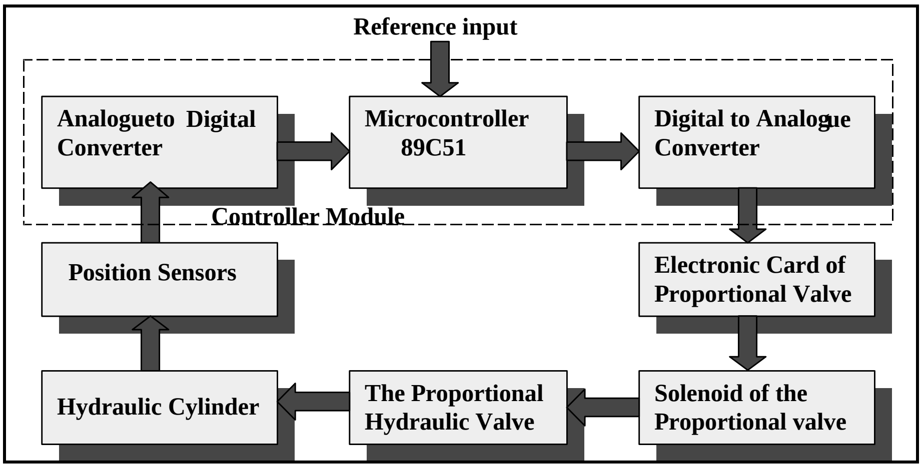


Figure (6) The block diagram of position control system

In order to control the position setting, the output voltage of the microcontroller is converted from digital to analogue type by the DAC circuit and the proportional valve solenoid will be actuated via the electronic amplifier card of this valve.

Only three external control lines were required to control the analogue to digital converter circuit (AD574A) as shown in **Fig.(7)**. One line was needed to select either 8-bit or 12-bit conversion. A second line was connected to the R/C line to control whether a conversion or output data should occur while the third line was connected to the chip-enable line to activate the wanted functions.

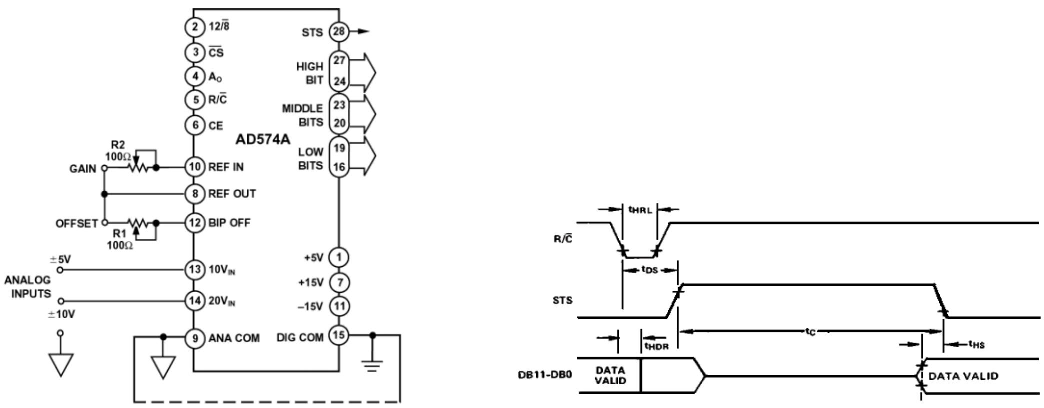


Figure (7) The connections and timing diagram of AD 574A [7]

The controller module of the position system uses the following power supplies

(1) +5V supply the microcontroller 89C51 and its support circuit.

(2) ±15V power supplies the interfacing circuit.

(3) +24V power, supplies the driver card of hydraulic proportional valve

The output pins of the digital to analogue circuit (DAC) are hard wired connected to an op-amp circuitry in order to tune the required gain and the result analogue output voltage signal from this circuit would be supplied to the electronic driver card of the proportional valve as shown in **Fig.(8)**.

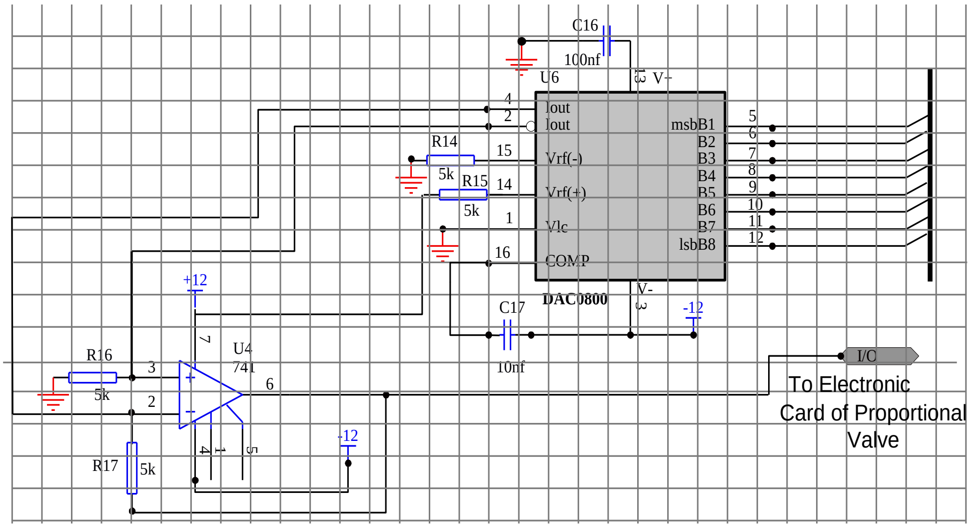


Figure (8) The connection diagram of the digital to analogue converter circuit

The 89C51microcontroller reads signals or data from its ports and sends the results as an output signals .All four ports P0, P1, P2 and P3 are bi- directional, as shown in **Fig.(9)** Pin 31 (/EA) of the MC 89C51 is a control pin, If /EA is logic ‘1’, the device looks for its program in internal EPROM. If /EA is logic ‘0’, the device looks for its program in External EPROM [8].

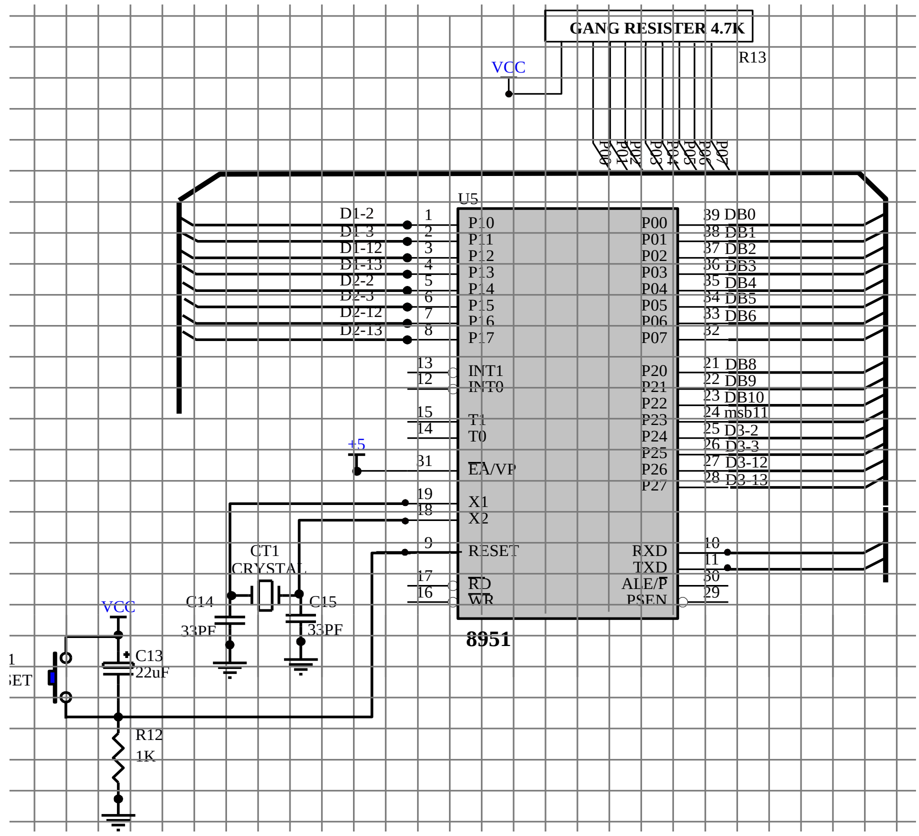


Figure (9) The microcontroller 89C51 subsystem

The microcontroller selects one of the position sensors of the hydraulic cylinder (either left or right) and sends a start signal to the A/D chip to begin converting the analogue voltage signals of the position sensor. When the conversion is completed the microcontroller stores the digital value from the A/D chip and compares the read data with the set point of the position.

The D/A converter interfaces with electronic amplifier card of the proportional valve to actuate the hydraulic cylinder until the required position is being achieved, After the hydraulic cylinder is being in position the microcontroller selects the next sensor and commands the A/D chip to begin the conversion. There are several types of sensors could be used to achieve the leveling such as Potentiometers, Capacitance sensors, Inductive distance measuring sensors and others [9]. The software design consists of three parts. The first part controls the A/D converter chip and reads the data from it, the second one compares the read data, and the third interfaces to the D/A converter. A laboratory work is made in hydraulic lab in engineering college of Al-Mustansiriyah University in Baghdad to investigate the performance of the hydraulic cylinder as shown in **Fig.(10)**.

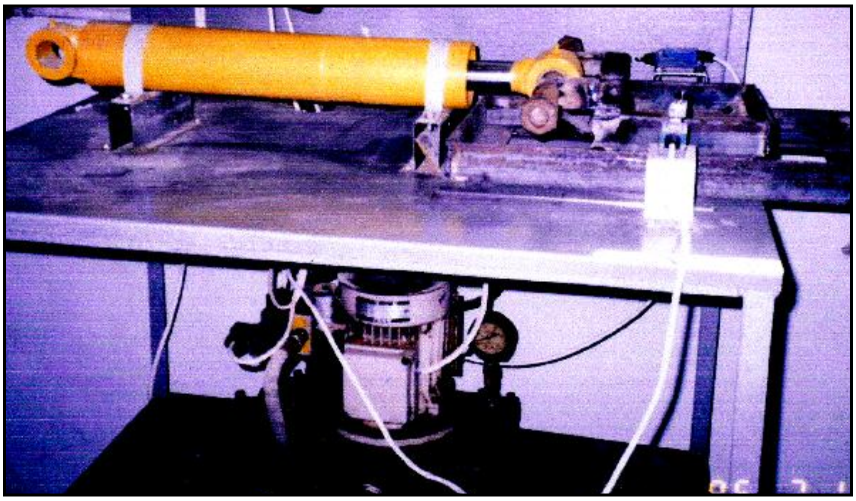


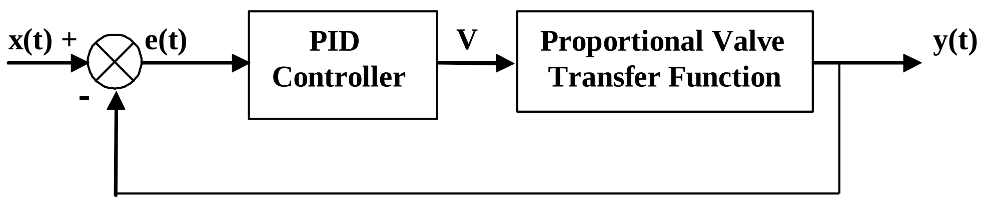
Figure (10) The hydraulic cylinder for position control system

4. Simulation Process

Simulation has been performed to investigate the performance of the electro-hydraulic subsystem for the position control system. The actuators, valves and cylinders were modeled using their parameters provided by the manufacturer. PID controller for the valve was included in the model and the transfer function was generated for that. The transducer gives a feedback signal to the PID controller, which is inserted in the forward path.

This was accomplished using SIMULINK/MATLAB, which prompts the user to modify the PID and the actuators parameters, and then the results are plotted in MATLAB. The simulation includes two steps, the first one is a MATLAB file that has the model of the transfer function and the second one is a SIMULINK graphics model that simulates the system step response.

In controlling an electro-hydraulic proportional valve the PID system was used to control the solenoid of the hydraulic valve in order to control the linear position of the valve spool tending to govern the flow rate of the hydraulic fluid, which passes the valve towards the hydraulic cylinder so that the position of the cylinder rod can be proportionally adjusted.



x - Desired Position. **y - Actual Position.**
e - Error = Desired Position (x) –Actual (y). **V- Solenoid Valve Voltage**

Figure (11) The block diagram of PID control system

As it has been shown in **Fig.(11)**, the PID output becomes a voltage applied to the solenoid of the hydraulic valve and the feedback signal is a linear position measured by an inductive positional transducer that is linked with the spool of the valve. The classic three terms (Proportional + Integral + Derivative) control algorithm uses three components: error, time integral of error, and time derivative of error [10]. The PID controller is defined by the following relationship between the controller input e (t) and the controller output v (t) that is applied to the proportional valve.

$$v(t)=Kpe(t)+Ki\int^{t} e(\tau)d(\tau)+Kd\frac{de(t)}{dt} \quad \text{.. (1)}$$

where:

Kp, Ki and Kd: are proportional, integral and derivative constants.

e(t): error signal between reference input and output voltage signal.

v(t): output voltage signal.

Taking the Laplace transform of equation (1) gives the transfer function:

$$\frac{V_{(s)}}{E_{(s)}}=\left(Kp+\frac{K_i}{s}+Kd_s\right) \quad \text{……………………………………………………... (2)}$$

The PID controller gains can be adjusted by changing the data and observing the behavior of the system to stabilize the control process to optimal behavior. The following MATLAB codes are used to simulate this system.

```
Kp=7;Ki=9;Kd=3;
num=[Kd, Kp, Ki]; den=[1, 1+Kd, 1+Kp, Ki];
numb=[2,5,5]; denb=[1,3,6,5]; numc=[2,2,1]; denc=[1,3,3,1];
numd=[1,5,1]; dend=[1,2,6,1]; numa=[1]; dena=[1];t=0:01:20;
syso=tf (num, den); sysa=tf (numa, dena); sysb=tf (numb, denb);
sysc=tf (numc, denc); sysd=tf (numd, dend);
y0=step (syso, t); y1=step (sysa, t); y2=step (sysb, t); y3=step (sysc, t);
y4=step (sysd, t); plot (t, [y4 y3 y2 y1 y0]); grid
xlabel (‘time (sec)'); ylabel (‘y (t)');title ('Proportional Valve Response');
```

A SIMULINK model has been performed for the simulation of the electro-hydraulic proportional valve subsystem as shown in **Fig.(12)**.

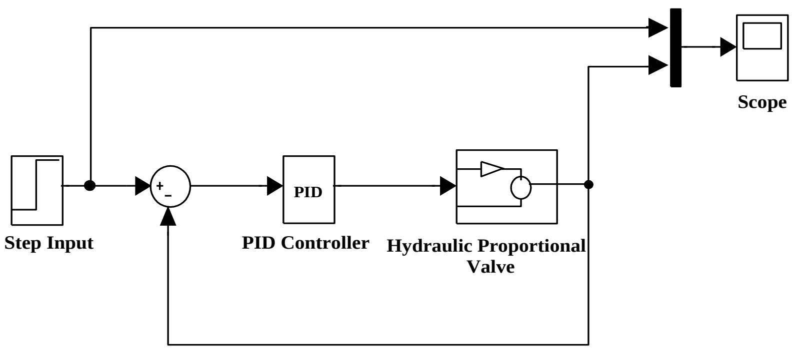


Figure (12) The proportional valve with PID controller model

The simulated results can be shown easily and quickly on the display. Different gains were taken on the PID controller that would change the dynamics and the stability of the control system as shown in **Fig.(13)**.

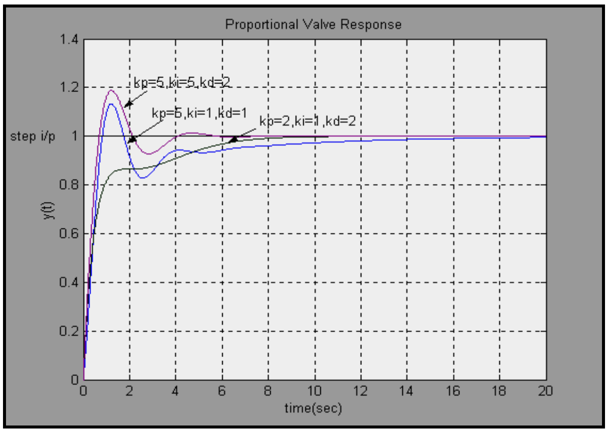


Figure (13) The proportional valve response

In order to simulate all blocks of the hydraulic subsystem, this model consists of the PID controller, proportional valve and the hydraulic cylinder and a system under consideration is shown in **Fig.(14)**.

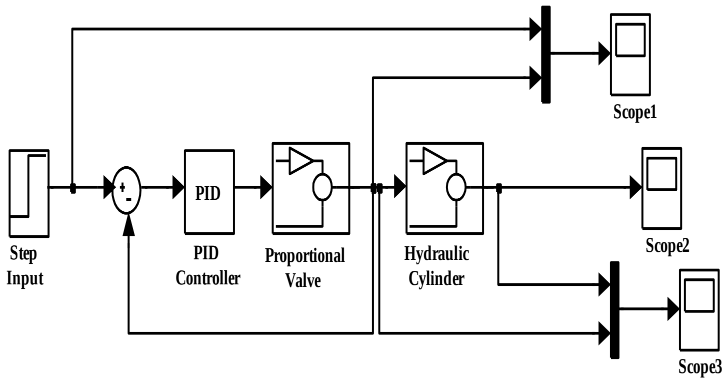


Figure (14) The proportional valve and hydraulic cylinder model

Different characteristics of the hydraulic valve and cylinder response such as rise time, steady-state error and peak overshoot are controlled by the selection of the three gains of the PID controller. The PID is tuned to give fast and smooth responses to a step input signal. The result of the simulation may be plotted as shown in **Fig.(15)**.

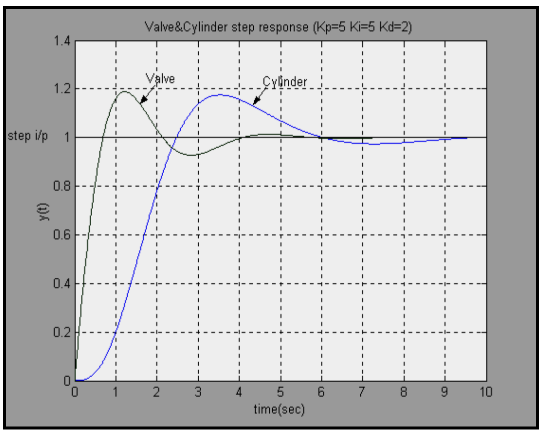


Figure (15) The valve and cylinder response

The transfer function of the hydraulic cylinder is considered as a second order function described as below and the stroke of the rod for the cylinder is linearly increased with respect to the time [3].

$$\frac{Y(s)}{X(s)} = \frac{K}{(s^2 + 2s\xi Wn + Wn^2)} \quad \text{...} \quad (3)$$

where:

K: namplification factor.

ζ: damping ratio for the cylinder subsystem.

Wn: natural frequency for the cylinder subsystem.

A step input signal was used as the reference input signal and the SIMULINK model file is specified in another M-file. **Figure (16)** shows the time constant (T1 and T2) for the proportional valve and hydraulic cylinder.

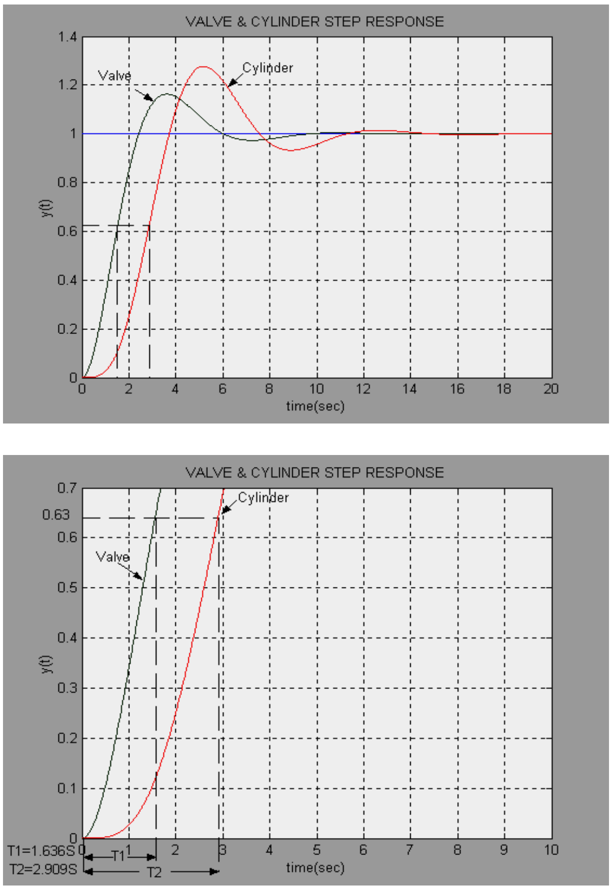


Figure (16) The time constant for the hydraulic valve and cylinder

5. Conclusions

1. This work is based on the design and implementation of a position control system of the hydraulic cylinder system that could be easily interfaced with a microcontroller module. The design centers around building an electronic controller module involving microcontroller and other peripherals interfaced with position sensor and a hydraulic proportional directional control valve,
2. Hydraulic proportional valve is chosen in this work to improve the performance of an electro-hydraulic system used in the position control module.
3. The design of the controller module for the position control system requires involving both hardware and software considerations. Investigation has shown the ability of implementing the controller module based on microcontroller for limiting the position of the hydraulic cylinder interfaced with "PID controller".
4. Simulation has been performed to investigate the performance of the electro-hydraulic subsystem that was used in position control system gave good results. Even though not much experimental work has been finished, a good start has been made and initial tests have been promising.
5. The results show that the controller of the system can be easily tuned by software and adjusted to meet the requirements for the position control of the hydraulic shafts. Very high accuracy was achieved where error could be due to backlash of the hydraulic shaft and the resolution of converting analogue signals to binary.

6. References

1. M. R., Sirouspour, and S. E., Salcudean, ***"On the Nonlinear Control of Hydraulic Servo-systems"***, Department of Electrical and Computer Engineering, British Columbia University, 1996, Available at E-mail: shahins@ece.ubc.ca, tims@ece.ubc.ca.

2. P. J., Costa Branco, and J. A., Dente, ***"Design of an Electro-Hydraulic System using Neuro-Fuzzy Techniques"***, Mechatronics Laboratory, Department of Electrical and Computer Engineering, Lisbon, Portugal, 2000.

3. Rexroth Staff, ***"Hydraulic Trainer-Proportional and Servo Valve Technology"***, Volume 2, Manesman Rexroth, 1986.

4. Rexroth Staff, ***"Hydraulic Trainer: Instruction and Information on Oil Hydraulics"***, Volume 1, Manesman Rexroth, 1981

5. Y., Sencer, ***"Programming and Interfacing the 8051 Microcontroller"***, Rigel Corporation, 1995.

6. Proportional Valve Technology, from CCI Valve Technology, Available at http://www.ccivalve.com

7. Complete 12-Bit A/D Converter AD574, Available at http://www.analog.com/ product selection /pdf/ad574a.pdf, Analog Devices.

8. T. W., Schultz, ***"C and the 8051: Hardware Modular, Programming, and Multitasking"***, Volume1, Prentice Hall Inc, 1998.

9. Alexander H. Slocum, Precision Machine Design, Topic 8, Sensor systems, 1994, available at http://www.yahoo.com.

10. E. A., Parr, ***"Industrial Control Handbook"***, Volume 2, BSP Professional Books, 1987.