Al-Khwarizmi Engineering Journal

Al-Khwarizmi Engineering Journal, Vol. 11, No. 1, P.P. 11- 18 (2015)

Stabilizing Gap of Pole Electric Arc Furnace Using Smart Hydraulic System

Maher Yahya Sallom* **Riyam Neamah Khaleel****

,Department of Mechatronics Engineering/ Al-Khwarizmi Engineering College/ University of Baghdad*

*Email: alabasy2001@yahoo.com

**Email: reyam.naima@yahoo.com

(Received 18 November 2014; accepted 15 February 2015)

Abstract

Electric arc furnace applications in industry are related to position system of its pole, up and down of pole. The pole should be set the certain gap. These setting are needed to calibrate. It is done manually. In this research will proposed smart hydraulic to make this pole works as intelligent using proportional directional control valve. The output of this research will develop and improve the working of the electric arc furnace. This research requires study and design of the system to achieve the purpose and representation using Automation Studio software (AS), in addition to mathematically analyzed and where they were building a laboratory device similar to the design and conduct experiments to study the system in practice and compared with simulation.

Experimental tests show that the performance of electro hydraulic closed loop system (EHCLS) for position control is good and the output results are good and acceptable. The practical results and simulation using (AS) software are clearly convergence. It was concluded that the possibility of the implementation of this project in industrial processes such as electric arc furnaces to control the distance between the pole and smelting molten material in addition to other applications.

Keywords: *Proportional valve, LVDT, Electro hydraulic, electric furnace, Automation studio.*

1. Introduction

Electric arc furnace [EAF] is used to produce metals such as steel by melting scrap using electrical supply [1], the graphite electrode, is used to converted electrical energy to extensive heat by means of high current electric arcs drawn between the electrode tips and the metallic charge. If closed loop position control is used, the position changes proportionally to input current. In the hydraulics industry, the term proportional valve refers to a specific type of valve which is quite distinctive to servo valves. Thus, when talking about proportional valves, it is talking about a solenoid activated valve with very distinctive operating characteristics [2]. The smart systems control the gap by controlling the amount of current flowing through the electric pole which should be designed using hydraulic system that consists of proportional directional control valve. The hydraulic proportional control valve can be used to describe any action where one parameter varies in some proportion to another. In the case of a servo valve, the spool position moves in proportion to the input signal [1]. The output of this system will develop and improve the work of electric arc furnace.

2. Electro Hydraulic Closed Loop System

Electro-hydraulic system is essential in engineering field because it can provide very high forces, high control accuracies, high power to weight ratio and also have a compact structure. Due to that reason, research for the control of force and position of electro-hydraulic system attract a great interest to both researchers and engineers [3].

A closed loop system, whether the reference signal is set manually or automatically, can perform control of cylinder position, speed and force [4]. Hydraulic closed loop or hydraulic servo system can be defined as any system with a servo or proportional valve. It consisted of a spool, and an outer sleeve with flow ports drilled in the sleeve. The position of the spool determines the flow areas and hence controls the amount of flow through the valve. The spool could be positioned in a number of ways.

The electro-hydraulic module of the position control system contains hydraulic cylinder and four ways, electrical solenoid hydraulic proportional valves with their electronic cards that transfer the signal 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 up and down with acceptable speed [5].

The term proportional valve that shown in figure (1). It refers to a specific type of valve which is quite distinctive to servo valves. The function of proportional valves is to provide a smooth and continuous variation in flow or pressure in response to an electrical input. The solenoids on these valves shift the spool more or less, According to the voltage applied to proportional solenoids, they can change the speed at which the spool shifts or the distance that it travels [6].

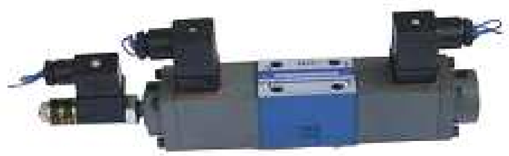


Fig. 1. The proportional control valve type (4WRE6E08-11/24Z4/M) with ratio 2:1 [7].

3. Test Rig of Hydraulic System

The main concept of proposal work is based on design the hydraulic system to control the position of gap. Figure (2) shows the proposal design. The components of this design shows in Table (1).

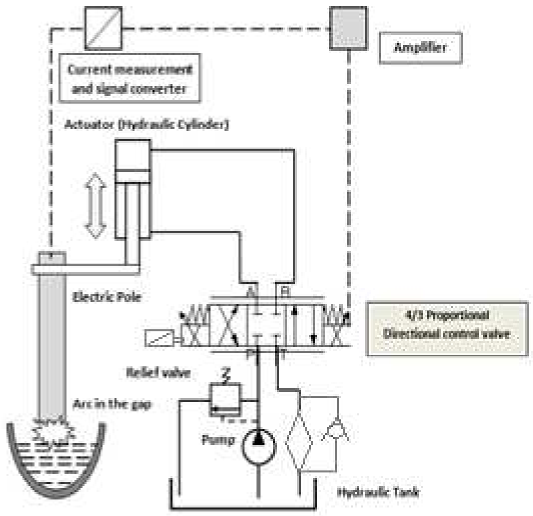
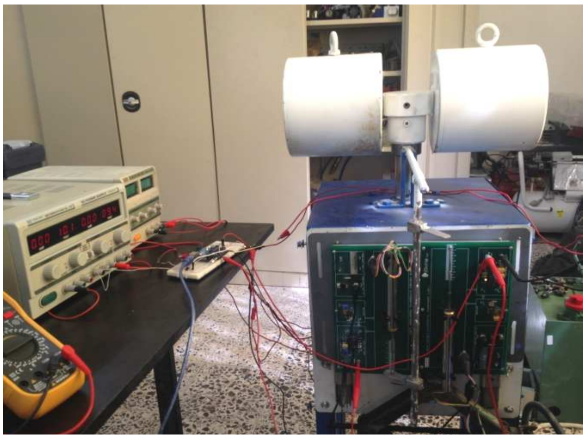


Fig. 2. The schematic of proposal design.

Table 1,
The component of hydraulic system.

Device	Specifications
Proportional directional control valve with proportional amplifier	4WRE6E08-11/24Z4/M, Rexroth Co., A-B-P operating pressure: 315, Control stroke: 4.5mm. Associated amplifier: 24 Volt, VT-5007
Hydraulic pump	Fixed displacement gear pump, 200 bar
Hydraulic cylinder	90mm piston, 45mm rod, 400mm stroke
Pressure relief valve	
Hydraulic Tank	Made of cost iron, 30 liters capacity

The rig is designed using hydraulic components as shown in Figure (3). It has been designed as like parts of the work and electric arc furnaces. Where designed the hydraulic system and connect all components with electronics parts that representative the movement of the gap in the arc furnaces. Directional proportional control valve used to control the direction and speed of the flow that pass to the hydraulic cylinder to control the movement of electrode in electric arc furnace.



(a)

(b)

Fig. 3. (a) Electro-hydraulic closed- loop system for position control test rig. (b) Connect valve and power unit with electro hydraulic closed loop rig.

The proportional directional control valve is used in the rig from REXROTH type (4WRE6E08-11/24Z4/M) [7] with ratio 2:1. The hydraulic cylinder is a part of hydraulic system used to convert the power of pressurized fluid to mechanical. The piston has two packing, facing in opposite directions, to seal the fluid in both directions. Hydraulic power units apply the pressure that drives motors, cylinders, and other complementary parts of a hydraulic system.

In addition to hydraulic power unit is a complete system with two ports, one for supplied flow to the hydraulic system and other for return flow from the hydraulic system. Electronic components that used in the design is a proportional amplifier has been used to control the circuit of the proportional directional control valves and the sensor (B3530) [9] linear variable displacement transformer LVDT that used in the test rig is used to measure the movement of electrode then convert the mechanical movement to electrical signal and gives the reading to a proportional amplifier.

4. Mathematical Analysis of Hydraulic System

In overrunning load, all proportional valve spools can meter fluid in and out as shown in Figure (4).

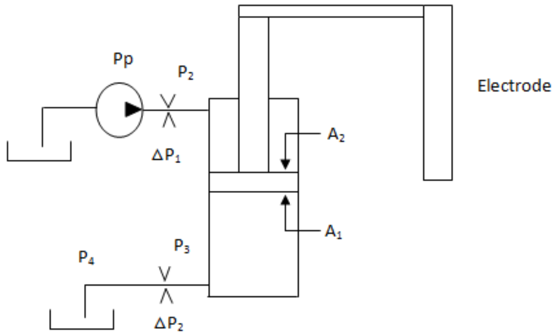


Fig. 4. Circuit diagram of potential overrunning load.

When using a 2:1 area ratio cylinder with a 1:1 area ratio spool [6],

$A_1 = A_2$

$Q_2 = 2Q_1$

There are two orifices:

$$Q_1 = CA_1\sqrt{\Delta P_1} \quad \ldots(1)$$

$$Q_2 = CA_2\sqrt{\Delta P_2} \quad \ldots(2)$$

Where:

Q- Flow of hydraulic cylinder in two directions (LPM).

C- Discharge coefficient.

A_1 & A_2- Area of hydraulic cylinder in two directions (mm^2).

ΔP- Pressure drop (bar).

Therefore

$A_1 = Q_1/\sqrt{\Delta P_1}$ And $A_2 = Q_2/\sqrt{\Delta P_2}$

$$Q_1/\sqrt{\Delta P_1} = Q_2/\sqrt{\Delta P_2} \quad \ldots(3)$$

$$Q_1/Q_2 = \sqrt{\Delta P_1}/\sqrt{\Delta P_2} \quad \ldots(4)$$

$$\Delta P_2 = 4\Delta P_1 \quad \ldots(5)$$

By summing forces, we solve P3.

$$(P_3 \cdot A_1) - (P_2 \cdot A_2) - F = 0 \quad \ldots(6)$$

$$P_3 = [(P_2 \cdot A_2) + F]/A_1 \quad \ldots(7)$$

Where:

F- The load of electrode (N).
Then determine:
$\Delta P_1 = P_p - P_2$
$\Delta P_2 = P_3 - P_4$; P_4=0
$\Delta P_2 = P_3$

Determined for 1:1 area ratio spools. Squaring both sides of the equation (3.24):
$Q_1/Q_2 = (\sqrt{\Delta P_1}/\sqrt{\Delta P_2})$
$(Q_1/Q_2)^2 = (\sqrt{\Delta P_1})^2/(\sqrt{\Delta P_2})^2$
$\therefore \Delta P_2 = [(Q_2)^2 \cdot \Delta P_1]/(Q_1)^2$ …(8)

Substituting the equation (3.28) in (3.27):
$P_3 = [(Q_2)^2 \cdot (P_p - P_2)/{Q_1}^2]$ …(9)

$(P_p - P_2)(Q_2)^2/(Q_1)^2 = (P_2 \cdot A_2 + \mathrm{F})/A_1$ …(10)

$P_2 =$
$[P_p(Q_2/Q_1)^2 - (F/A_1)]/[(A_2/A_1) + (Q_2/Q_1)^2]$ …(11)

For 2:1 area ratio cylinder controlled by a valve with a 2:1 area ratio spool:
$Q_2 = 2Q_1$
$A_2 = 2A_1$ Or $A_1 = A_2/2$
Therefore
$A_2 = (Q_2/\sqrt{\Delta P_2})$ …(12)

$A_1 = \frac{A_2}{2} = (Q_1/\sqrt{\Delta P_1})$ …(13)

$\frac{Q_2}{2Q_1} = \frac{\sqrt{\Delta P_2}}{\sqrt{\Delta P_1}}$ …(14)

$\therefore \Delta P_1 = \Delta P_2$ …(15)
$\therefore\ (P_p - P_2) \cdot {Q_2}^2/(2Q_1)^2 = [(P_2 \cdot A_2) + F]/A_1$ …(16)

$P_2 =$
$[P_p \cdot (Q_2/2Q_1)^2 - (F/A_1)]/[(A_2/A_1) + (Q_2/2Q_1)^2]$ …(17)

In resistive load, for 1:1 ratio valve.
$P_3[(P_p \cdot Q_1^2/Q_2^2) +$
$(F/A_h)]/[(Q_1/Q_2)^2 + (A_C/A_h)]$ …(18)

For 2:1 area ratio valve resistive load:
$P_3 =$
$[P_p \cdot (Q_2/2Q_1)^2 -$
$(F/A_1)]/[(Q_2/2Q_1)^2 + (A_2/A_1)]$ …(19)

5. The Simulation of Electro Hydraulic Closed Loop System

The hydraulic system is designed and simulated using the program (Automation Studio Package 5.2). It has been designed as the same concept parts of the work and electric arc furnaces. Where designed the hydraulic system and linked them with joystick that representative the movement of the gap in the arc furnaces. Figure (5) explains the design and operation of the system in an Automation Studio.

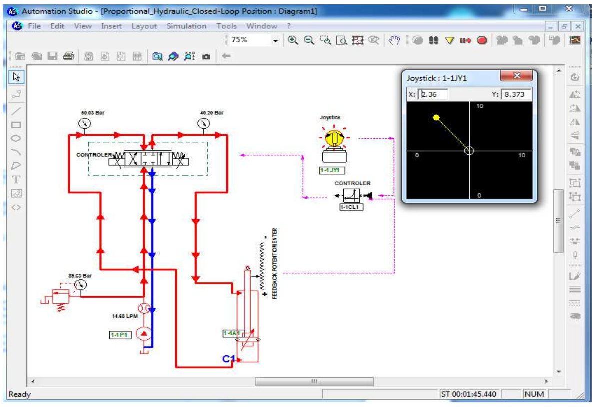


Fig. 5. The simulation in Automation Studio.

A typical hydraulic circuit of the test rig in AS is drawn by changing the position of joystick in x-axis and y-axis to change the position of actuator (hydraulic cylinder), these positions lead to operate the hydraulic system and remain until returning the proportional valve to reference. Results are drawn in the form of a graph showing the effect of movement on the pressure and flow of each component.

6. The Experimental Work of Electro Hydraulic Closed Loop System (EHCLS) For Position Control

The objective of this test is to study the characteristics of the combination between the hydraulic cylinder and proportional directional valve for best performance for position control hydraulic system .Two cases have been studied, when the cylinder moved at high-speed and at low-speed. During the operation of the hydraulic system, voltage and pressure signals are taken from LVDT sensor and pressure sensor respectively. Signals send to ARDUINO and process them programmatically. Then the out results are drawn as the graph on computer to explain the relation between the parts with respect to time.

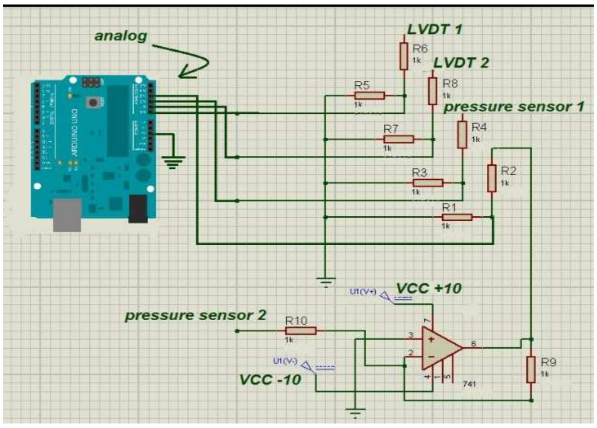


Fig. 6. The connection of electronic circuit.

6. Results and Discussion

As the results figure (7) shows the relation between duration times vs. output volts of LVTD. During operation of hydraulic cylinder up and down, LVDT measure the movement and convert it to electrical signal that display by using ARDUINO direct on computer. The curve start from low value and increasing up to highest value until the hydraulic cylinder stopped when the stroke measured was (97.8mm). When repeated the test more than once, the value be close. The train of curve means the nature of movement.

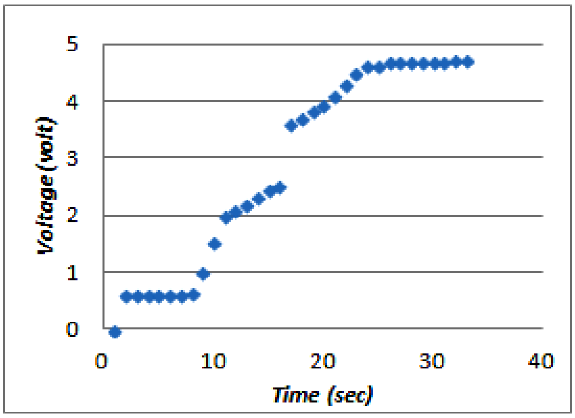


Fig. 7. Variation of LVDT signal with input movement at time.

The applied pressure of hydraulic pump range (5-3 bar) during the system operation and (10 bar) when stopped according to cracking pressure of relief valve. For calculated the speed of movement of cylinder that used these values to calculate the flow using these equations:

$$V = \frac{D}{T} \quad \dots (20)$$

And

$$Q = A \times V \quad \dots (21)$$

Area in the case of the descent of the cylinder calculated from:

$$A = A_1 - A_2$$

When increasing the distance (gap), the input signal value of proportional amplifier change leads to the opening of the valve and flow the liquid at high speed, the cylinder move and therefore have high volumetric flow rate then the speed decreased gradually to stand when it reaches the specified distance as well as the volumetric flow. The relation of position with time assigned shown in figure (8). The position with time can be speed according to equation (20) as shown in figure (9). As well as the flow calculated according to equation (21) as shown in figure (10). From both of two figures the trains going down in high slop and after 5 second become slow with graduate until steady state. This means the proportional valve is closed proportionally to input signal that comes from LVTD.

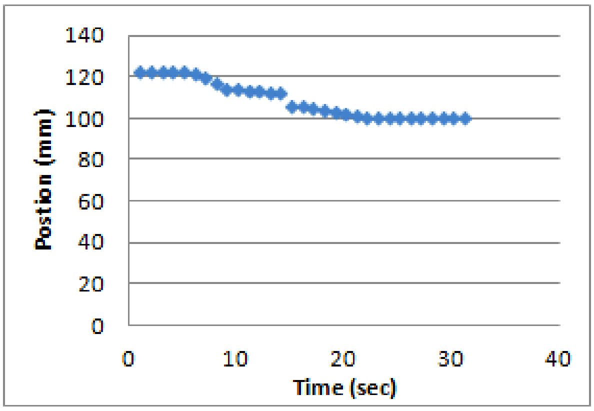


Fig. 8. Variation of cylinder position with value input signal.

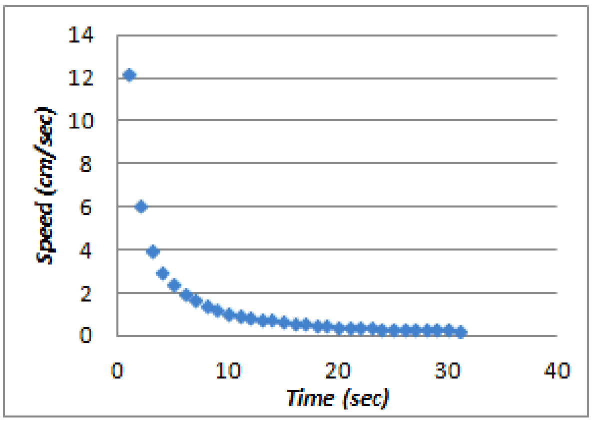


Fig . 9. Variation of cylinder speed with input signal.

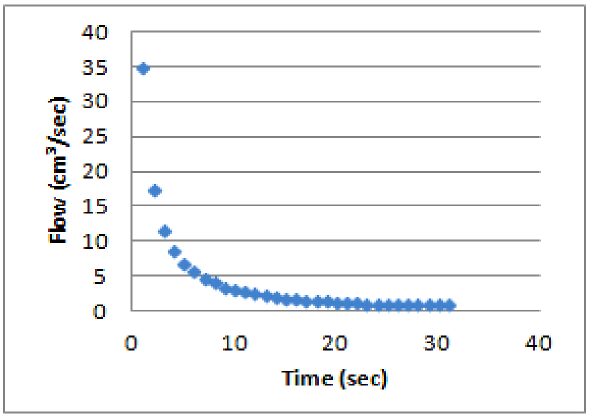


Fig. 10. Variation of cylinder flow with value input signal.

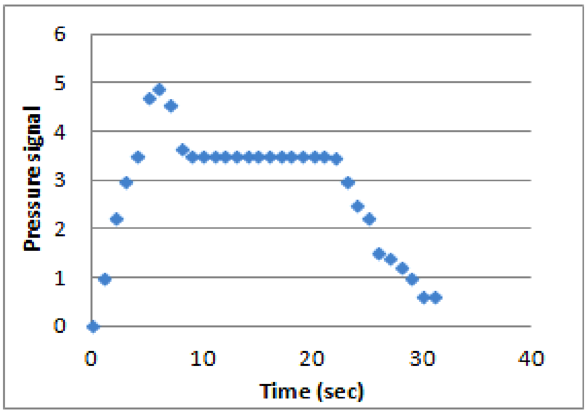


Fig . 11. Variation of pressure of hydraulic system with input signal.

There is a high pressure drop across the orifice cause to high flow rate that makes the system is unstable. The high pressure and flow because the load applied is low on proportional amplifier. The load applied has a small effect on the results. When the load increased, the high load applied low pressure load which cause low flow rate and make the system is stable. Figure (11) shows the behavior of pressure system at input port of hydraulic cylinder. It is appear that the high pressure in start moving because of moving from rest, and going down as steady state until low when stop.

A comparison between experimental and simulation results show convergence in results clearly. The purpose of this comparison is to see the behaviors of the system. The position is agreed between experimental and simulation results as shown in figure (12). The difference comes because the valve in the simulation not exactly in the test but in same function. The speed is convergent with variations between two results. The highest value for the speed arrives in simulation is (14.6 cm/sec) and more than the result in practical this is because the speed of movement joystick fast compared with the motion sensor in practical as well as for flow curve depending on equation (21) that illustrate relationship between the speed and flow. Figures (13) and (14) show the comparison of speed and flow as well Figure (14) shows for pressure.

There is a difference between the values due to high flow rate in simulation that caused high pressure and the accuracy of program (AS) in the measurement compared with the measured pressure in the practical.

The experimental results are represented the real behavior of the system under many nonlinearity factors like friction effects between the oil and hoses and oil compressibility, while the simulation results represent the simulation process for the system depends on input data for all components in the simulation program. There is difference in the results between experimental and simulation results.

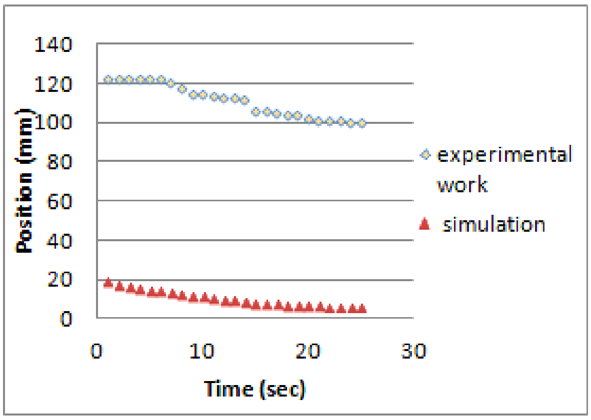


Fig. 12. Comparison in position between experimental and simulation results.

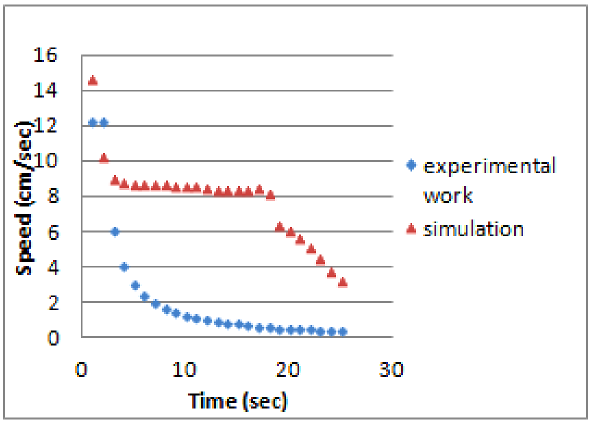


Fig. 13. Comparison in speed between experimental and simulation results.

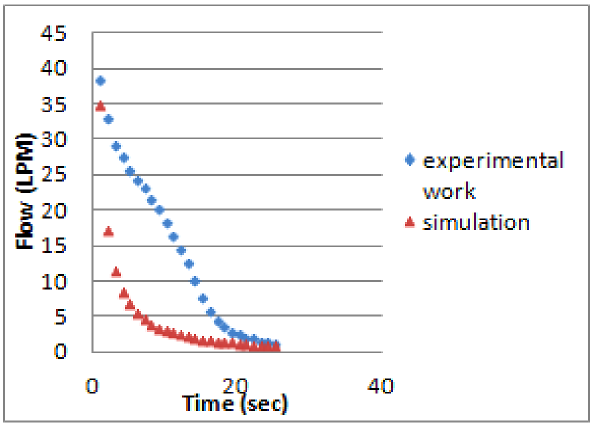


Fig. 14. Comparison in flow between experimental and simulation results.

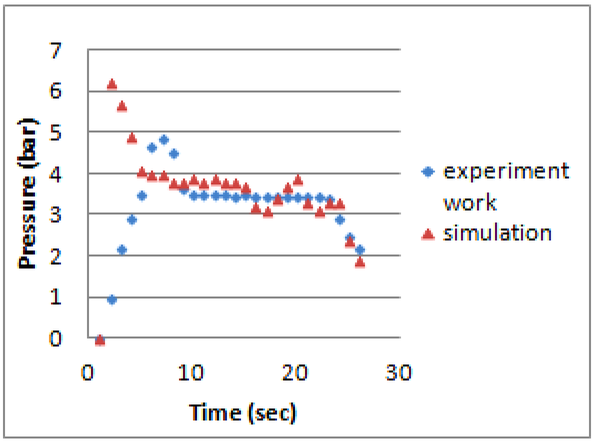


Fig. 15. Comparison in pressure between experimental and simulation results.

7. Conclusion

The control of position by used electro closed loop hydraulic system is important mechanism in industrial applications. The hydraulic component and electronic interface must be chosen and arranged carefully. An experimental and theoretical work has been conducted to design position control by used closed loop hydraulic system with directional proportional control valve.

Experimental tests show that the performance of (EHCLS) for position control is good and the output results are good and acceptable. The practical results and simulation using (AS) program are clearly convergence. This leads us to the possibility of using this program for testing and analysis and design of any hydraulic system. It provided the introduction of the real values of the same parts of the system in the program to give the correct results.

8. Reference

[1] S. R. Billings and H. Nicholson, " Modeling a three-phase electric arc furnace: a comparatives of the control strategies," Applied Mathematical Modeling, val.1, pp. 355-361, December 1977.

[2] M. Peens, I.K. Craig and P.C. Pistorius , "Modeling and Control of an Electrode System for a Three-Phase Electric Arc furnace", Pretoria, South Africa, December 2004.

[3] Rozaimi Ghazali, Yahaya Md. Sam, Mohd Fua'ad Rahmat and Zulfatman "Open-loop and Closed-loop Recursive Identification of an Electro-hydraulic Actuator System", lohor, Malaysia, 2010.

[4] Medhat k. Bahr Khalil "Interactive Analysis of Closed Loop Electro-Hydraulic Control System", pp. 1, 2009.

[5] M. Gullon " Hydraulic Servo System Analysis And Design " , Butterworth Co , London , United Kingdom, 1969.

[6] Michael J. Tonyan, "Electronically controlled proportional valves, selection and application", Rexroth Worldwide Hydraulic, Industrial Hydraulic Division, Bethlehem, Pennsylvania, 1985.

[7] Directional proportional control valve, May, 2014, http://www.hshydraulic.com/valves/Proportional-directional-valves.htm .

[8] D.H. Ewald R. "The Hydraulic Trainer Volume 2– Proportional and Servo Valve Technology" Mannesmann Rexroth GmbH, 1986.

[9] LVDT, May, 2014 http://www.efunda.com/designstandards/sensors/lvdt/lvdt_theory.cfm.

استقرار فجوة قطب فرن القوس الكهربائي باستخدام منظومة الهيدروليكية الذكية

ماهر يحيى سلوم* ريام نعمة خليل**
*،**قسم هندسة الميكاترونكس/ كلية هندسة الخوارزمي/ جامعة بغداد
*البريد الالكتروني: alabasy2001@yahoo.com
**البريد الالكتروني: reyam.naima@yahoo.com

الخلاصة

التطبيقات فرن القوس الكهربائي في الصناعة ترتبط بوضع القطب وحركته صعودا وهبوطا. يجب تعيين موقع محدد للقطب. اعداد ذلك يتطلب معايرة تتم يدويا. في هذا البحث اقترح منظومة هيدروليكية ذكية لجعل هذا القطب يعمل ذكيا باستخدام صمام السيطرة الهيدروليكية الاتجاهي التناسبي. إخراج هذا البحث طبق في فرن القوس الكهربائي. يتطلب هذا البحث دراسة وتصميم نظام لتحقيق الغرض والتمثيل باستخدام برنامج (Automation Studio 5.2) بالإضافة إلى تحليلها رياضيا وحيث تم بناء جهاز وختبري مماثل لتصميم وإجراء التجارب لدراسة النظام عمليا و مقارنة مع Simulation.

من الاختبارات التجريبية تبين ان أداء (EHCLS) للسيطرة على الموقع واخذت النتائج العملية وقورنت مع نتائج Simulation وكانت متقاربة ومقبولة. علاوة على إمكانية تنفيذ هذا المشروع في العمليات الصناعية مثل أفران القوس الكهربائي للسيطرة على المسافة بين القطب وصهر المواد المنصهرة اضافة الى التطبيقات الأخرى.