



## Manufacturing of Electro-hydraulic Elevator System Controlled by PLC

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### ABSTRACT

Hydraulic actuators are one of the most viable choices due to their high power-to-weight ratio, low cost, robustness, fast response and great power supply. The present work focuses on building an elevator prototype model simulates real hydraulic elevator. This model consists of hydraulic parts (double-acting hydraulic cylinders, pump, valves, pipeline and filter) and electronic parts (PLC, push-bottoms, relays and encoder). It is built with three floors in about 300 cm height (total with the cylinder) to elevate a 30 kg payload and controlled by a PLC controller of (DELTA DVP-ES32) with 16 inputs and 16 outputs. The PLC receives input signals as orders from the operator as well as sensors and encoders. The PLC is programmed with WPSOFT 2.46 Ladder diagram software to basically calling the elevator cabin through three locations and enabling its arrival at the desired floor. The cabin descent is achieved by using a proportional control valve which is controlled by the PLC. The cabin door is automatically opened and closed by DC motors. It is observed that, the application of this partnership between the PLC and the proportional valve in the build model helped to achieve excellent results in terms of system control and its efficiency, response, and smoothness.

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### 1. Introduction

The practice of converting hydrostatic fluid power into translational or rotational mechanical power is ubiquitous in many industries today. This is typically done through a hydraulic actuator in hydraulic communication with an appropriate hydraulic circuit, and in mechanical communication with its surroundings, such that desired motion is achieved [1]. The hydraulic elevator, a typical mechatronic system with embedded controllers, is one of the most popular types of elevators [2]. Since the 1980s, with the rapid development of modern science and technology, especially the perfection of electrohydraulic proportional technology, the hydraulic elevator, along

with modern high technology, has been improved in safety, reliability and operating performance [3,4]. Nowadays more and more scientists, enterprisers and international enterpriser groups go in for its development, research, production and marketing [5]. The hydraulic elevator has suffered from high inefficiency, a significant part of which stems from a heavy reliance on throttling-based control where the control can be improved in terms of elevator speed, runtime, position precision, position overshoot, vibration compensation, comfort level, reliability, safety, power consumption and robustness. Until now, several control approaches have been used, such as variable structure control [6], the traditional PID

controller [7-9], and adaptive impedance control [10] were applied to hydraulic systems.

This paper describes the development and manufacturing of a complete model of an electro-hydraulic system employed in an elevator which focused on controlling of the volumetric speed developed by a proportional valve controlled by PLC controller that is cooperated with a double-acting hydraulic cylinder for wave energy conversion

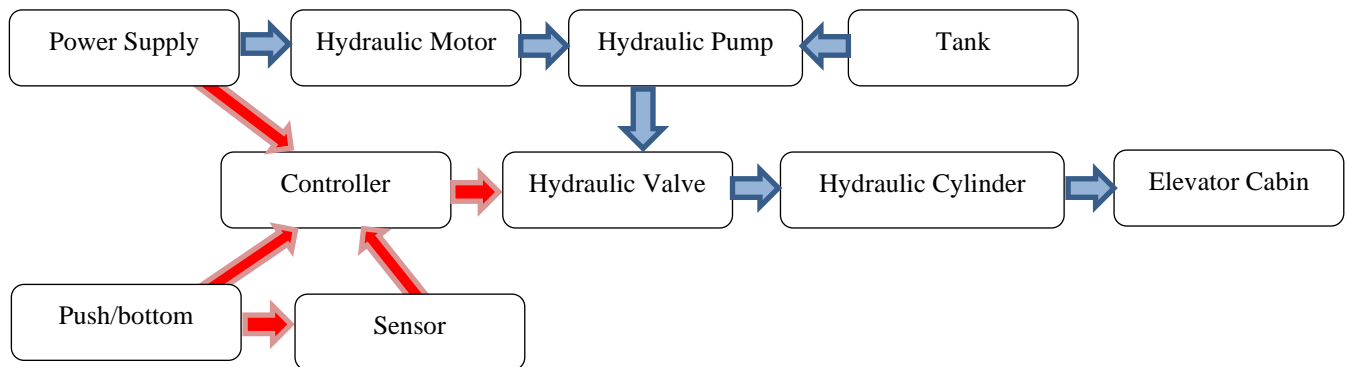


Fig. (1): Electro-hydraulic elevator system block diagram.

The cylinders are the elements that cause motion and prepare the real desired work. In order to control the movement and speed of the cylinder, it is possible to use the double acting cylinder for this purpose, especially the piston rod on single side of double acting cylinder type which cooperates with a proportional valve. The pump forces oil from the tank into a pipe leading to the cylinder. When the valve is opened, the pressurized oil will take the path of least resistance and return to the reservoir. But when the valve is closed, the pressurized oil has nowhere to go except into the cylinder. Toward extending the cylinder, the pump flow will be sent to the blank end port as proposed in Fig.(2-a). The fluid returns to the reservoir from the rod end port. To tract the cylinder, the pump flow sends to the port of rod end and the fluid returns to the tank from the blank end port as explained in Fig. (2-b).

When the oil flow pushes the piston up by affecting the theoretical force, the output of a cylinder can be calculated by the following steps:

. This model is an extension of other models in which losses were assumed to be constant and independent of the hydraulic system pressure and flow.

## 2. Operation principle of the Hydraulic Elevator

The hydraulic elevator system includes various parts that described in Fig. (1).

$$\text{Output Force} = \text{Area} \times \text{Pressure} \dots (1)$$

The theoretical thrust/Force F is given as [11]:

$$\text{Double acting thrust (out stroke)} \quad F = (\pi D^2 p) / 4 \quad (2)$$

$$\text{Double acting pull (In stroke)} \quad F = (\pi (D^2 - d^2) p) / 4 \quad (3)$$

Where:

F = Cylinder Thrust in N.

D = Diameter of Piston in mm; D= 38mm

d = Diameter of piston rod in mm; d= 25mm

P = Operating Pressure in bar; the maximum pressure for the used vane pump is 50 bar = 5 N/mm<sup>2</sup>.

Thus:

$$A = \frac{\pi \times D^2}{4} = \frac{\pi \times 38^2}{4} = 1134 \text{ mm}^2$$

$$F = 5 \text{ N/mm}^2 \times 1134 \text{ mm}^2 = 5670 \text{ N}$$

The payload mass can be calculated as [12]:

$$m = F/g \dots (4)$$

Where:

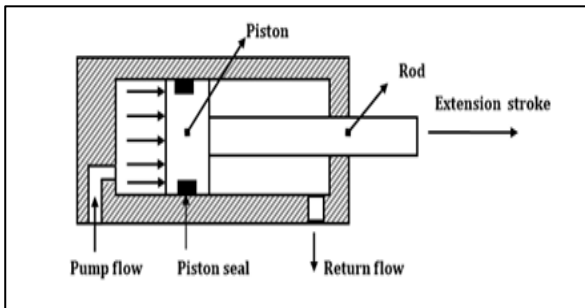
F: the force in Newton.

m: the mass of payload in kg.

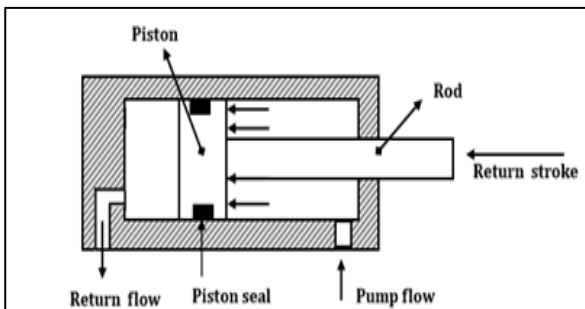
g: the gravity (approx. equal to 10 N/kg).

Therefore:

$m = 567 \text{ kg}$  for maximum pressure (50 bar) =  
 $11.34 \text{ kg}$  for a pressure of 1 bar.



(a) Extension the cylinder



(b) Retraction the cylinder

Fig. (1): Double-acting cylinder with a piston rod on one side

### 3. Modeling of the Electro-Hydraulic System

The electro-hydraulic elevator (EHE) model controlled by a PLC is consisting of hydraulic, mechanical and electrical parts as follows:

#### 3.1 Hydraulic parts

The main driving force of the equipment is provided by the hydraulic system. It's composed of cylinder, tank, filters, valves and hydraulic pump. Fig. (3) shows the schematic diagram of the proposed elevator model.

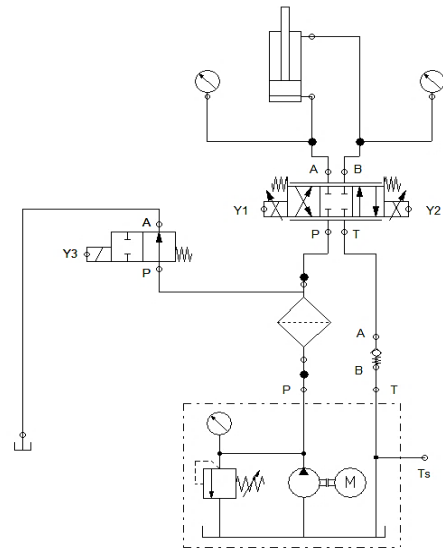


Fig. (3): Schematic diagram of the EHE.

#### a. The Tank and Filters

The hydraulic tank is designed according to system need for oil which has four holes; two of them are for pouring oil out/to the tank with filter and the other two holes are for entrance the oil into the system from the pumps or pouring oil out of the system (from cylinder). The tank is designed from iron according to its strength with dimensions (L40 cm x W20 cm x H50 cm). It's works with the existence of two types of filters to remove unwanted objects and materials as well as dust mixed with oil. Pull filter is located inside the hydraulic tank where the oil passes through before being pumped by the pump. This filter has a specification such as the nominal pressure is (100 bar), filter rating is about (10 $\mu$ ) and the displacement is (350 l/min). The second one is the pressure hydraulic filter which is located between the pump and the hydraulic valves where the nominal pressure for this filter is (100 bar).

#### b. The hydraulic pump and motor

Another hydraulic component is the hydraulic pump that is considered as the beating heart of the hydraulic system. Figure (4) shows a variable displacement vane pump that have been used in the hydraulic system elevator based on its easy maintenance and proper price. Since the flow rate for this pump is (8 lpm), and

in order to obtain a suitable speed for the cabin, two variable displacement vane pumps were mixed together when the flow rate outside of the pump is (16 lpm) and the maximum operating pressure is (50 bar). In addition to the hydraulic motor that is placed above the tank and connected with the hydraulic pump to operate it. Moreover, the hydraulic motor is equipped with a single phase AC power supply.

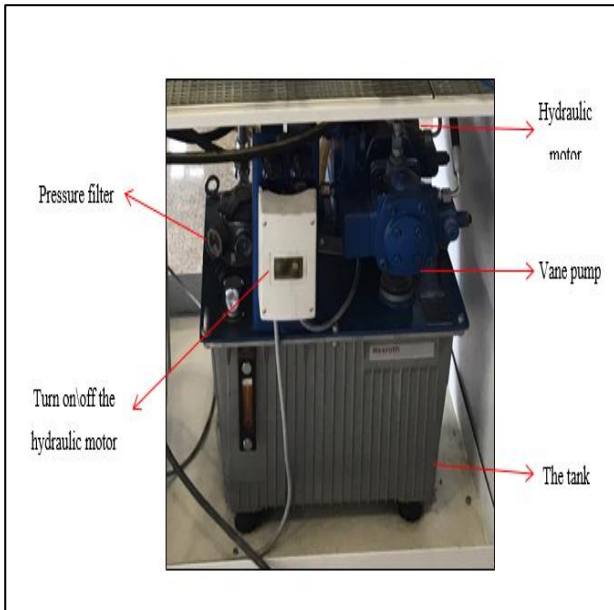


Fig. (4): The pump with the Hydraulic motor.

### c. The hydraulic valves and cylinder

The hydraulic valves and the hydraulic cylinder are the major equipment of the hydraulic system that they were rarely used together in elevator systems at the previous researches. The unloading and proportional valves are employed in the experimental work. The first is receiving the oil after leaving the pump and passing the oil to the proportional valve. The function of this valve is reducing the pressure of oil as well as protecting the elevator system while the second is connected with the hydraulic cylinder (in both ports A, B) directly from one side and with the unloading valve and tank from the other side as shown in Fig. (5).

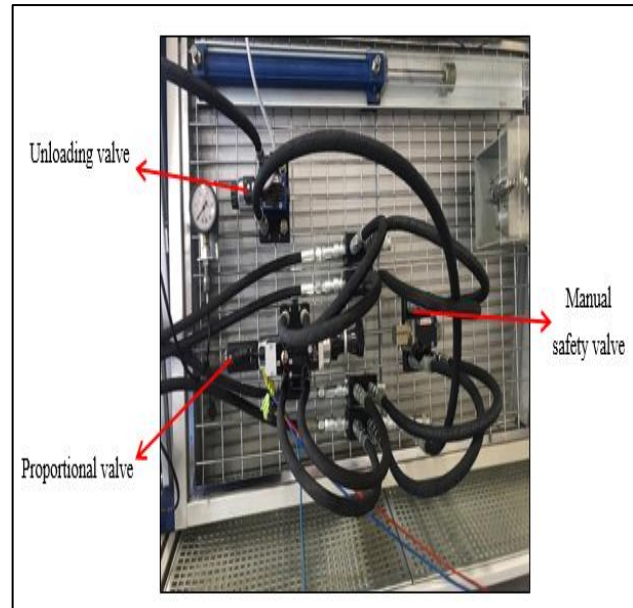


Fig (5): The valves connection.

The proportional valve in this system has two functions, controlling the direction of oil in order to control the movement of the cabin likewise controlling the size of the oil (through controlling the opening of the port A,B) in order to obtain a smooth and jerk-less cabin movement especially at the starting and stopping. The proportional valve is controlled by PLC which has ability to pass (35 Lpm).

The double-acting hydraulic cylinder is constructed with (118 cm length). This cylinder also has two opening ends at the top and at the bottom of the cylinder as proposed in Fig. (6).

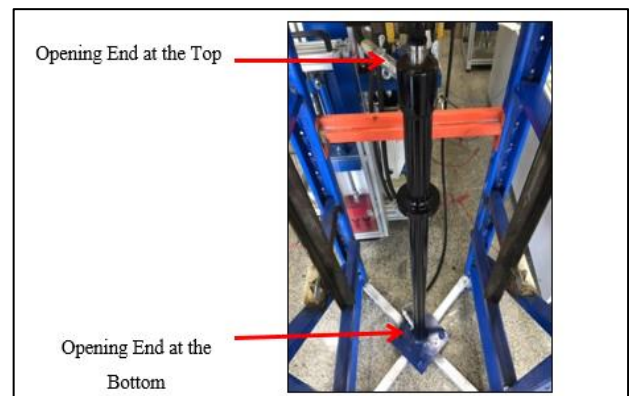


Fig. (6): Double-acting hydraulic cylinder.

The cylinder's structure of the elevator model as listed in Table (1) was tested in the Company for Inspection and Engineering Rehabilitation (SIER) and it's found the cylinder consists of medium strength carbon steel

material (steel CK55). The medium strength carbon steel metal is chosen because of it's stronger than low carbon steel and not brittle like high carbon steel. The external cylinder can be used with different lengths according to requirement of the model design.

Table (1): Hydraulic actuator specification.

Parameters	Values
Piston diameter	38 mm
Rod diameter	25 mm
Stroke	107 cm
Overall mass	15.5 kg
Maximum operation pressure	150 bar

### 3.2 Mechanical Parts

The mechanical system is composed of the elevator cabin, cabin door, and the elevator frame as shown in Fig.(7). The construction steel was chosen to build the cabin according to its strength and more durable than the other metals. It has a high resistance to pressure and low breaking possibility where it had been designed with dimensions of (30 cm×30 cm). The cabin door cut with dimensions of (24 cm×24 cm). The elevator car has to move with a maximum velocity of 4 cm/s, the weight of the elevator cabin is 2 kg.

In this paper, the cabin door is not the main objective of the model design. Thus, for simple construction, the author found that the more efficient design for cabin door to be compatible with the controller (PLC) is the CD (Compact Drive). This door drive will be easily controlled by PLC program for opening and closing function.

The frame that was designed with (300 cm length – 66 cm width – 67 cm depth) dimensions. Also, railings (guide) were installed on both sides of the inside structure in order to make the movement of the car in linear path and more smoothly. These guides were fixed on the frame by using brackets of (5 mm).

### 3.3. The Electrical Parts

The elevator electrical parts connection is presented in the rear of the building. The electrical connection includes the following devices.

#### a. The Encoder

The cylinder used in the elevator model system has length of (118 cm length) with two opening ends one is at the top and the other at the bottom. One of the problems that might be problem is the ability to stop the cabin at specific point. The pump of oil makes it difficult to stop the piston at a certain point. To solve this problem, the encoder utilized to recognize those stories borders for each floor. An encoder of (Kori-E40S) type is consisting of the disk, the element of encoder; small load and rope as shown in Fig. (7).

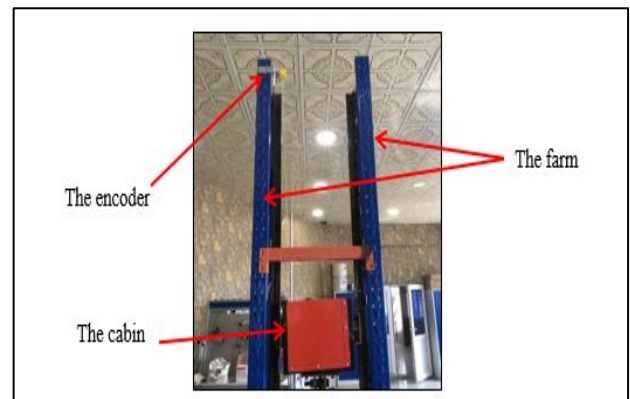
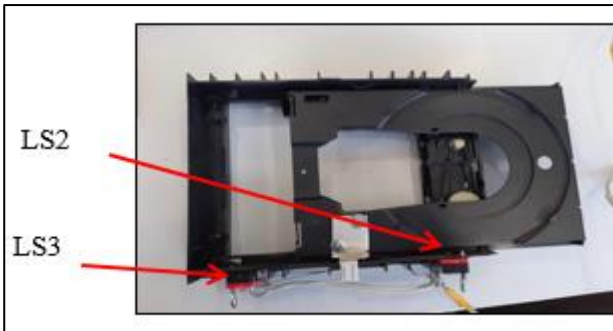


Fig. (7): The outer construction of the elevator.

#### (b) The Limit Switch

Three limit switches were used in the electro-hydraulic elevator system in different places and for several functions. Every limit switch was named in numbering and in PLC program. The first limit switch (LS1) was placed at the top end of the frame. (LS2) and (LS3) switches were placed in the DC cabin door. When the cabin reaches any floor, the door will open and during that the door touches the (LS2) which in turn sends a signal to the PLC that the door opened. After passing four seconds, the door will close and touch the (LS3) to send a signal to the PLC that the door closed as shown in Fig. (8).





(a) The limit switch with DC door



(b) A single limit switch

Fig. (8): The limit switches.

### c. The controller

The programmable logic controller (PLC) systems are the brain, as well as the elevator central controller. The PLC is a programmable device that could be attached to the PC and reconfigured to meet the work specifications. The type of the PLC used for the model is (DELTA DSP-ES32) series with 16 inputs and 16 outputs. Its operator program is (WPSOFT 2.46) in Ladder language.

A power supply is used to supply all the system with the DC power from AC source. Some components were used in the elevator model are working on AC power like (PLC and the hydraulic motor). Other components are working on DC power like (PLCs input-proximate switches-the card for outside and inside call buttons). The power supply specifications are: Input 200-220 V, 50Hz Output +24 V, 5A.

Finally, the mechanical specification for the electro-hydraulic system are listed in Table (2)

Table (2): Mechanical Specification of the Elevator System.

Elevator Cabin		Elevator Frame	
Height	30 cm	Height	300 cm
Width	30 cm	Width	66 cm
Length	45 cm	Length	67 cm
Cabin material	Construction Steel	Frame material	Construction Steel
Cabin weight	Approx.2kg	No. of floors	3+G
Load weight	30 kg	Max. Velocity	4 cm\s

## 4. Experimental Testes and Results

The laboratory elevator model have been built where its setup is equipped with Multisystem 5060 device (to convert analog output quantities in the current model, such as the (flow and pressure read from the flow and pressure meter sensor) into digital signals to be compatible with PC for plotting results (with the help of HYDROTECHNIK program).

By running the prototype elevator system with different proposed floor level patterns, some results

such as the flow and pressure curves with time for different cases of loading have been obtained. The used load cases include the no-load and 30 kg load. In the no-load case, the total weight of the cabin includes cabin itself added to the weight of the door of the cabin door as well as the weight of the connections. All these weights are almost determined by (2kg).

For analyzing the oil flow (green color curve) and pressure (black color curve) in the elevator system for the No-load case, the flow curves as shown in Fig.(10) can be divided into 9 intervals. In these curves, the oscillations represent the movement of the elevator where the peaks are in motion while the bottoms are in

stop situations. The floor level pattern is proposed as (Ground→ floor 3→ floor 2→ Ground→ floor 1), In this case, the maximum flow of about (5.5L/min) is existed in the interval (3 ~ 17 sec), where the cabin moves from the rising mode at the ground floor to the third floor and then immediately drops to zero when it arrived and stopped in the third floor at the interval of (17 ~ 20 sec). On the other hand, the interval with (38 ~ 48 sec), the cabin steps down again in the direction of ground floor with pressure of (11 bar) then drops to maximum value of about (16 bar), and stopped in the interval of (48 ~ 51 sec).

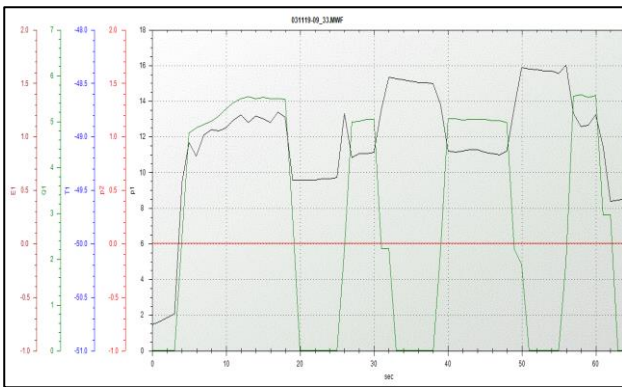


Fig. (10): No-load flow and pressure curves with floor level pattern (G→3→2→G→1).

In the case of 30 kg, the floors sequence is different from the first one as the following (Ground→ floor 2→ Ground→ floor 3→ floor 1). It's observed that the stability and the oscillation of the curves are better compared to the no load case. This is due to the large capacity of the hydraulic system and its efficient operation at high weights.

It can be seen from Fig. (11) that the maximum flow ranges are about 5.6 L/min when rising towards the second floor level and similarly with the same rate at coming back down to the Ground floor level of (22 ~ 30 sec). At the same time, pressure will increase to the maximum of (17 bar) when the cabin of the elevator moves down from the second floor to the ground. It is worth mentioning that the door of the cabin was closed by using the automatic mode (the timer closed the door after passing 3 sec).

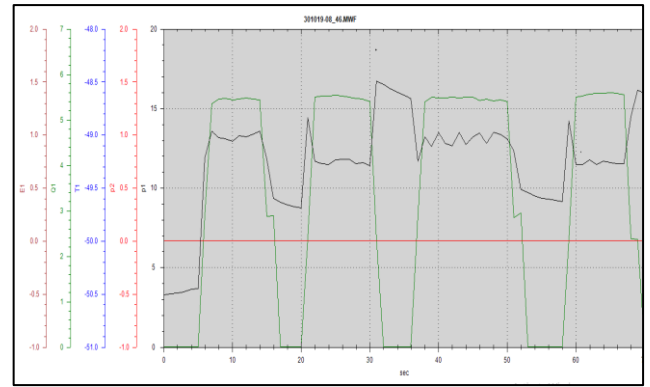


Fig. (11): The flow and pressure curves at payload of 30 kg with floor level pattern (G→2→G→3→1).

In Figs. (10 and 11), it can be seen that the curve representing the oscillations of pressure in the upward movement is smaller than that in the downward movement. When the elevator starts, the cabin descends suddenly at the moment that static frictional force is changed into dynamic frictional force. The impacting force is very large. It may be as large as two times the weight of the cabin.

The phenomenon mentioned above does not exist in upward movement. On the other hand, the energy for upward movement comes from the power source, and is large enough for the cabin to run. However, the energy for downward movement comes from the weight of cabin itself, and it is not enough for cabin to run. Therefore, the control of the upward direction is much easier than the control of the downward direction. As discussed above, the speed control of the downward direction is more difficult than the speed control of the upward direction.

## 5. Conclusions

From the current research work, certain points have been concluded:

1. The proposed PLC based hydraulic elevator system is successfully implemented as a prototype model; it is fully automated with three floors.
2. It is observed that, the application of this partnership between the PLC and the proportional valve helped to achieve excellent results in terms of

system control and its efficiency, response, and smoothness.

3. The current elevator has high portability in lifting high weights compared to other elevators, thus it's used in buildings and factories that use high loads.

4. It can be seen from the obtained results of load cases that increasing of load causes increase in the flow rate and flow overshoot. Likewise, it can be shown that the flow overshoot happens when the cabin is at the beginning of descending mode.

Table (3):List of Abbreviation

Abbreviation	Discretion of Abbreviation
PLC	Programmable Logic Controller
EHS	Electro-Hydraulic System
CD	Compact Drive
LS	limit switch
G	Ground

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