NEW CONSTRUCTION OF PNEUMATIC RESIDENTIAL ELEVATOR SYSTEM

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ABSTRACT :-

The current paper presents a new construction of an Electro-Pneumatic (EP) elevator system fully automated with Programmable Logic Controller (PLC) technology. This elevator represents as a new concept derived and evolved from the pneumatic-vacuum elevator as the idea of vacuum air is changed by the pressed air. The elector-pneumatic elevator is capable of transporting people between floors without using any cables, counter weight, or pulleys. An elevator system prototype constructed with three floors to elevate a 5kg payload with 1bar pressure had been proposed and controlled via a PLC controller of (LS-GLOFA-G7M-DR20A), 8 inputs, and 12 outputs. The PLC was programmed with Ladder diagram software. The idea of the proposed elevator system may be predicted to be widely spread in the low-rise residential buildings .

KEYWORDS: Automated, Low-rise, Electro-pneumatic elevator .

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الخلاصة :-

البحث الحالي يمثل بناء جديد لمنظومة مصعد كهروهوائي ومتحكم به بشكل تام باستخدام تقنية المتحكم المنطقي المبرمج. المصعد الكهروهوائي يمثل فكرة جديدة مشتقة ومطورّة عن المصعد الهوائي وهذا يتم استبدال فكرة الهواء المفرغ بفكرة الهواء المضغوط. المصعد الكهروهوائي يمكنه نقل الاشخاص بين الطوابق بدون استخدام الحبال والاوزان والبكرات. تمّ اقتراح نموذج لمنظومة مصعد مكونة من ثلاثة طوابق لرفع حملة تصل الى 5 كغم وبضغط هواء 1 بار ومتحكم به من قبل متحكم منطقي مبرمج من سلسلة (LS-GLOFA-G7M-DR20A) ذو ثمان مداخل واثنا عشر مخرجاً. تمّ برمجة المتحكم باستخدام برنامج لادر (Ladder). يُتوقع أن تكون الفكرة المقترحة لمنظومة المصعد الحالية أكثر انتشاراً واسعاً في البنايات السكنية ذات الارتفاعات المنخفضة.

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INTRODUCTION:

Pneumatic (F. Ebel, 2000) is a science branch dealing with the behavior of gases specifically, air, and its characteristics and applications at pressure either greater (pressurized) or less (vacuum) than atmospheric pressure. The pneumatics is preferred in comparison with the hydraulics, because:

1- The pneumatic can be simply joined to a compressor air supply.
2- It has no need for separated power set.
3- Fast response of pneumatic actuators.
4- Has no need for return piping, whereas, the air is released to atmosphere.
5- It leaks with clean medium and has no clutter.
6- It is un-acceptor for burning.

Electro-pneumatics EPs (G. Prede and D. Scholz, 2005) may be defined as pneumatic components controlled by electrical impulses. The EPs uses all electronic components like micro-controller, sensors, relays, electronic switches, transformers. The control system of the EP involves electric control systems driving pneumatic power systems. Therefore, the EPs became widespread in several fields especially in inexpensive industrial automation. Solenoid valves are needed as matching device between the electrical systems and pneumatic systems. Instruments as proximity sensor and limit switch are required as feedback tools. In the EPs, the working medium is the compressed air. One of the more important advantages of the EPs is be in the integration of different kinds of proximity sensors with a PLC for high effective control. The automated systems (F. Ebel at el., 2008) depending on the EP technology are basically formed from three groups: actuators "motors", sensors "buttons" and control elements "valves". The PLC today becomes alternative tool for controlling elements which is used to carry out the system logic. Many researchers had discussed the application of the PLC in the elevator control system. One of the modern and important applications for the pneumatic systems is the Pneumatic "Vacuum" elevator (Mid-American Elevator CO., 2016 and DAYTONA CO., 2016). It is specially, one type of the domestic elevators employed in places to elevate things or persons up to four stories. In this elevator there is no need for machine room, since it transports through building using driving machine composed of turbines located at the top of cylinder "hoist way" producing low pressure on the top of car "cabin", causing the cabin to transport up due to the ambient atmospheric pressure. It has no need for infrastructure, no pit, no energy dissipated through descent and less power needed for the ascending, panoramic visibility, largest safety when power is shutdown, less maintenance and no need for lubrication. The revolutionary technology in the Pneumatic Vacuum Elevator begins with using it in the indoor and outdoor domestic and commercial purposes round the world. Many researchers designed elevators running with different drives and controlled by a PLC. (T.R.F. Neto and R.S.T. Pontes, 2007) had been designed a prototype for roped type elevator. The traction machine used was a linear induction motor. This design established a new concept for elevators via a modern structure technique and assembly of the elevator with counterweight. (G. Singh, et al., 2013) focused on using Siemens LOGO PLC loaded by software LOGO Soft Comfort V7.0 for controlling and building the elevator system based on a DC motor to drive the elevator car toward up and down. (S.B.R. Carter and A. Selvaraj, 2013) constructed an elevator driven by an AC motor and fully automated by a PLC programmed with VersaPro 2.02 ladder logic software. (S. Sehgal and V. Acharya, 2014) were used the Supervisory Control and Data Acquisition SCADA for supervising and controlling the elevator work derived by a DC motor. Interfacing the PLC and SCADA with the elevator system made the elevator had very high response on any fault may happen. (M. Ahsan Ullah and M.A. Saeed, 2014) efficiently designed and implemented a high speed and low cost three floor elevator based on a PLC state diagram depending on FPGA by using

Xilinx StateCAD tool. (S. Htay and S.S.Y. Mon, 2016) basically focused on the use of a PLC for controlling and building a four floors elevator system. Hall Effect sensor was used to predict the position of the elevator car. A DC motor was used to translate the car up and down. The only research work in the literature talk about implementing an EP elevator controlled by a PLC was worked by (P. MATOUŠEK 2010). He designed and constructed a PLC based EP elevator model controlled via using a mobile phone. The current research work implements a new pneumatic elevator by making the air inside the actuator with pressure higher (compressed) than the atmospheric, instead of using the vacuum elevator (Mid-American Elevator CO. 2016 and DAYTONA CO. 2016), in which, the air pressure is lower (vacuum) than the atmospheric. The proposed elevator named by the EP elevator may be operated by an actuator (with fitted cabin (car) slotted on it) creating a high pressure under or over the cabin, causing the car to move upwards or downwards, respectively. The present work focused on the use of the electro-pneumatic components to build an elevator prototype setup controlled by a PLC, has three stories with (126cm) height. The PLC was programmed with Ladder language (GM WIN 4.0). A (LS\GLOFA-G7M-DR20A) PLC was used in this paper with 8 inputs and 12 outputs.

MODEL CONSTRUCTION

The proposed elevator model was assembled and constructed to simulate the real life of the actual elevator. This elevator is modeled as a laboratory prototype controlled by a PLC, combining the pneumatic components and electronic components. The material and devices used to build the system of the elevator model were as: PLC, power supply, air compressor, actuator, solenoids, relays, proximate switches, connectors, hoses and wires, cabin switches, and calling switches, regulator, distributors, indicators directly linked to the air compressor with an arm works as a brake in the emergencies, guide to support the movement of the cabin in ascend and descend, pressure switch and tray, as shown in Figure (1). Most of the EP components used in the current model were assembled from the FESTO Company (F. Ebel 2000, G. Prede and D. Scholz 2005, and F. Ebel at el. 2008). All the equipment specifications are listed in the Tables (1) and (2).

The elevator aluminum frame has been designed with (152cm length, 34cm width, and 47cm depth) and a travel length of (126cm). The cylinder (actuator) fixed on the frame, about (19cm) far from the frame front and fixed on plastic card board as shown in Figure (2a). The cylinder which has (126 cm) length was divided into three equal sections. Each section represents a (42cm) story in the building model. The proximate switches were used to identify these stories limits for the cabin. The switches are fixed on aluminum (L) shaped supports on the edge of each floor. Table (3) describes the mechanical dimensions and specifications for the elevator system .

The current model was constructed as a prototype system and can be used in the laboratory for educational purposes. This makes the wires and connections in the model close to each other and risk of being entangled and undefined. This problem can be solved by a useful way named (numbering). Different types of colored buttons were used as shown in Figure (2a). The green buttons fitted with LED. Each one of them is fixed in a different floor of the building model. These buttons are similar to the real buttons of the elevators. Every button in charge of calling the cabin to the floor by the passengers; the problem that may be faced in building the proposed prototype model is that, there are another buttons which must be fixed inside the real elevator. These buttons work like that one's outside the cabin in calling the cabin by the passengers. The priority in following command is for the buttons inside the cabin model which is small in size. Therefore, it was hard to attach the buttons inside the prototype elevator. To solve this problem, the buttons were fixed to the left of the cabin as small green buttons which were smaller than the floors' buttons and they are not fitted with (LED). A red switch fixed in the middle of the front base of the model is used to turn (on\off) the elevator. The PLC stores several commands during the experiment. The red switch turns off the system allowing the user to cancel those commands.

Electro-pneumatic Components :

The electrical connection for the elevator parts can be shown in the back side of the prototype elevator model shown in Figure (2b). These parts can be listed as below:

i.The Solenoids: The cylinder used in the elevator system has two openings; one is at the top and the other at bottom. The air compressibility prevents the actuator piston to stop at specific point. Therefore, two solenoids might be used at each opening point to resolve this problem as shown in Figure (3). The elevator solenoids must be connected to the cylinder in such way, which allows for a sending and descending of the cabin and to achieve this goal, a solenoid must be attached to the bottom opening and the compressor for one side. When the solenoid is provided with an air, it pushes the piston upward which results in lifting the cabin in the same direction. Since the air is highly compressible, another solenoid must be attached to the top opening for leaking the air above the piston. The descending is similar to the sending for the cabin. A solenoid is attached to the top opening of the cylinder and to the compressor from the other side. The piston is pushed down by the compressed air pulling the cabin down with it. Another solenoid is attached to the bottom opening vent the air to ensure the descent. Four normally closed solenoids were used; each two of them fixed to a distributor. The researcher found, experimentally by trying, that, the best distance between the solenoids to get the best air usage was of (21 cm).

ii.The Relays: Three relays used in the elevator model were distributed as follows: The first relay (relay up) is responsible for the cabin ascending for turning on both first solenoid and fourth solenoid (SV1 and SV4). The second relay (relay down) is responsible for cabin descending to turn on both of second solenoid and third solenoid (SV2 and SV3).The third relay, which responsible for opening and closing the cabin’s door (relay open and relay close), as shown in Figure (2b).

Programmable Logic Controller (PLC):

The PLC is the systems' brain and the main controller of the EP elevator. The PLC shown in Figure (2b) is programmable device which can be connected to the Personal Computer (PC) and reprogrammed to fit the work requirements. Inputs like sensors and switches and outputs like solenoids, relays are terminated with the PLC.

The Air Compressor:

The air compressor is the systems’ heart. The air compressor supplies the system with a compressed air. It is suitable to use an air compressor, with the proposed elevator model, has less size and less noise and provides the elevator with the suitable needed average pressure. The used compressor shown in Figure (4) gives a pressure range of (1-8 bar) .

Brake and Guide:

Many emergencies might happen during the elevator running, like: 1- Power outages, 2- A hole or a cut in the hoses connected to the solenoid, 3- A defect in the PLC, 4- The PLC stops, and 5- Conflict in instructs and repetition in orders, etc.

There are different ways to make safety. In the current research, a special solenoid with an arm was used. This arm is fixed through guide. When a problem happens, this defect is sensed by a pressure switch; it senses the difference of air pressure from the preset pressure thus extending. The solenoid arm come inside the solenoids' body through fixed guide, as a result, the brake stopped cabin in same place (the nearest floor) where the problem happened and prevent it from falling. Guide was fixed to the right of the cabin to maintain the cabin position and avoiding the sliding of the cabin as shown in Figure (5). The guide also can be used to stop the cabin from falling in the emergencies.

PNEUMATIC SCHEMATIC DIAGRAM:-

The schematic diagram of the proposed elevator model can be shown as in Figure (6), where the numbers shown in the figure are known as follows: 1- the air compressor, 2- Filter Regulator Lubricant (FRL), 3- 2/2 one way valves (NC) spring return back, 4- 2/2 one way valves (NC) spring return back for vent, 5- vent, 6- road less double ended cylinder, 7- Inductive proximate switch, 8- flow control valves, and 9- pressure gauge.

SOFTWARE PROGRAM OF ELEVATOR SYSTEM:-

Firstly, the software program starts, via using sensors, scanning the floors status, motion up and down, open and shut the cabin door, and then executing the Ladder software program in the PLC in order to control the total motions with time.

There are three main significant stages in the EP elevator control: 1- Signal inputs: generated from switches, different types of contacts and proximity sensors, 2- Signal processing: by using integration of relays and PLC, 3- Signal outputs: used for activating solenoids, relays, and indicators. The algorithm flowchart shown in Figure (7) illustrates the whole control steps which will be implemented in the elevator system.

RESULTS AND DISCUSSION:-

The experimental setup for the EP elevator prototype is shown in Figure (8). The elevator model setup was equipped with Analogue to Digital AD transducer (to convert analog output quantities in the current model, such as the (air flow rate is read by the air flow meter) into digital signals to be compatible with PC for plotting results (with the help of Matlab package) by using PC-based Data Acquisition (DAQ) System.

For getting and analyzing the experimental results, it was necessary to interface the PC into the system via serial USB interface.

By running the prototype elevator system shown in Figure (8) with two proposed floor level patterns for no-load and load cases, some results such as the air flow rate curves had been obtained as shown in Figs. (9)-(11). The used loading cases were with 2kg and 5kg (max. allowable load weight).

In the no-load case, the total weight of the cabin includes cabin itself added to the weight of brake and the cabin door as well as the weight of the connections. All these weights were almost determined by (0.3kg). Firstly, the elevator was running on no-load with the following proposed floor level pattern; (floor 1 → floor 3 → floor 2 → floor 1 → floor 2).

Applying this sequence to the no-load case (~ 0.3kg) requires a pressure with about (0.05 bar). The instantaneous air flow curve is shown in Figure (9). For analyzing the air flow in the elevator system for the above figure, the flow curve can be divided into 9 intervals as follows: In the interval from (0 ~ 2 sec), the elevator is at the rest in the first floor level with about zero value of air flow. In the interval (2 ~ 9 sec), the cabin is in the rising mode from the first floor to the third floor with maximum flow of about (4 L/min) and then immediately drops to zero when it arrived and stopped in the third floor position in the interval of (9 ~ 14 sec). In the interval (14 ~ 17 sec), the cabin steps down in the direction of second floor with maximum flow of (15 L/min) and then drops to minimum value of about (4 L/min), and stops in the interval of (17 ~ 21 sec) with zero flow. In the interval (21 ~ 27 sec), the cabin steps down again in the direction of first floor with maximum flow of (18 L/min) and then drops to minimum of about (4 L/min), and stopped in the interval of (27 ~ 35 sec) with zero flow. In the last step, the interval with (35 ~ 38 sec), the cabin goes back to the second floor with approximately (4 L/min) and then finally stops at zero flow in the interval of (38 ~ 40 sec). It can be concluded from the curve that, there is a very small flow overshoot in the step up mode and high flow overshoot in the step down mode of the cabin. By increasing the payload to (2kg) and the corresponding pressure into (0.45 bar) with a floor level pattern (1→3→2→1→2), Figure (10) can be obtained Finally, increasing the payload to (5kg) may require a pressure up to about (1 bar) and the following floor level pattern is proposed (1→3→1→2→1) to get the flow curve as shown as in Figure (11). It can be seen from the obtained results for the load cases, that increasing the load causes increase in the air flow rate and flow overshoot. Also, it can be shown that the flow overshoot happens when the cabin is in the beginning of descending mode.

CONCLUSIONS :-

A new EP elevator system, fully controlled by a PLC, had been presented and implemented successfully as a three floors prototype elevator. The construction of the EP elevator model is a new concept derived and evolved from the pneumatic elevator as the vacuum air concept is substituting with the pressured air. The EP elevator may transport people between floors without using any cables, counter weight, or pulleys. It is fixed on any flat floor and has no need for excavating any pit and does not require any engine room.

It was shown that, the PLC based EP elevator excellently performs work and operates smoothly, quietly with efficient ride with no any noticeable jerk in its motion. From the obtained results for the load cases, it can be concluded that the increase of load causes increase in the air flow rate and flow overshoot. Also, it can be shown that the flow overshoot happens when the cabin is in the beginning of descending mode.

It is very important to benefit from this kind of elevators in the industries, specifically in the domestic applications. So, deep experimental and validated studies may be needed when this kind of elevator systems are used in the commercial applications. The present elevator system may be predicted to be widely spread in the residential buildings like the indoor and outdoor use in both domestic and commercial elevators.

The present elevator system prototype may be utilized as instructional material in the departments of the electric engineering and electromechanical engineering to enhance learning the undergraduate students.

In the case of designing a real elevator, it is desirable to apply another PLC as a suggestion for future work, so as to protect the elevator system. When fault happens to the first PLC, the elevator takes orders from the other PLC .

Table (1): the Pneumatics Components

Pneumatic Components	Company	Specification
Air Compressor	ROLLS	Direct driven air compressor (1-8) bar
Actuator	HOERBIGER\ORIGA	126cm length has two opening with one piston (double ended piston rod cylinder) work in max 8 bar
Solenoids	HLPC	Normally open AC 220V, 50HZ
Pressure switch	DUNGS	LGW 10 A2 / Pmax = 500 mbar Luft
Compressed-Air Digital Flow Meter	T-CDI-5200-10S	Inputs: 0.25 A, 24 V DC, Max. output resistance: 600 Ω

Table (2): the Electrical Components

Electrical component	Company	Specifications
Relay	Murrelektronik	24 DC
PLC	LS \ GLOFA - G7M - DR20A	12/inputs, 8/outputs Programmed in (GMWIN 4.0) Ladder language
Power supply	Anlixun	s-120-24 I\P 110V AC, 1.6A, 230V AC 0.8A 50\60 HZ DC (5A)
Proximate switch	ABB	Inductive proximate switch
Electrical brake	FESTO	Especial solenoid with arm, 220AC
DAQ	National Instruments	NI USB-6008, 8 analog inputs (12-bit, 10 kS/s) 2 analog outputs (12-bit, 150 S/s)

Table (3): the Mechanical Specifications of the Elevator Prototype

Elevator's Cabin		Elevator's Frame	
Height	8cm	Length	152cm
Length	14cm	Width	34cm
Width	15cm	Depth	47cm
Cabin Material	Fiber glass	Travel Distance	126cm
Fiber glass Density	0.55 (Ib/In^3)	Frame Material	Aluminum
Cabin Weight	0.2 kg (approx)	Aluminum Density	2710 kg/m^3
Max. Load Wight	5 kg	Max. Velocity	0.05 m/sec

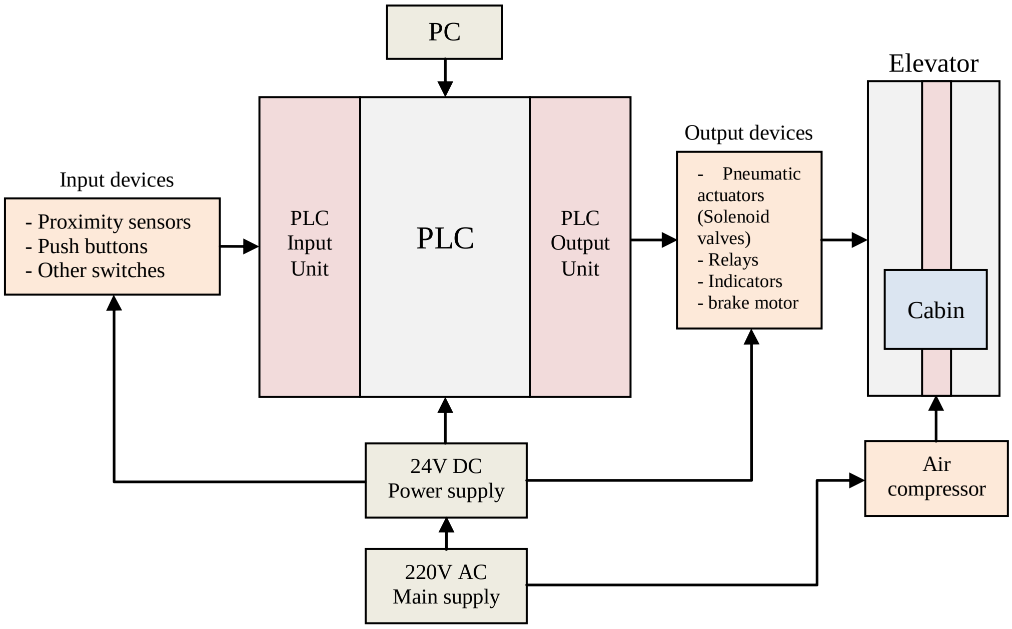
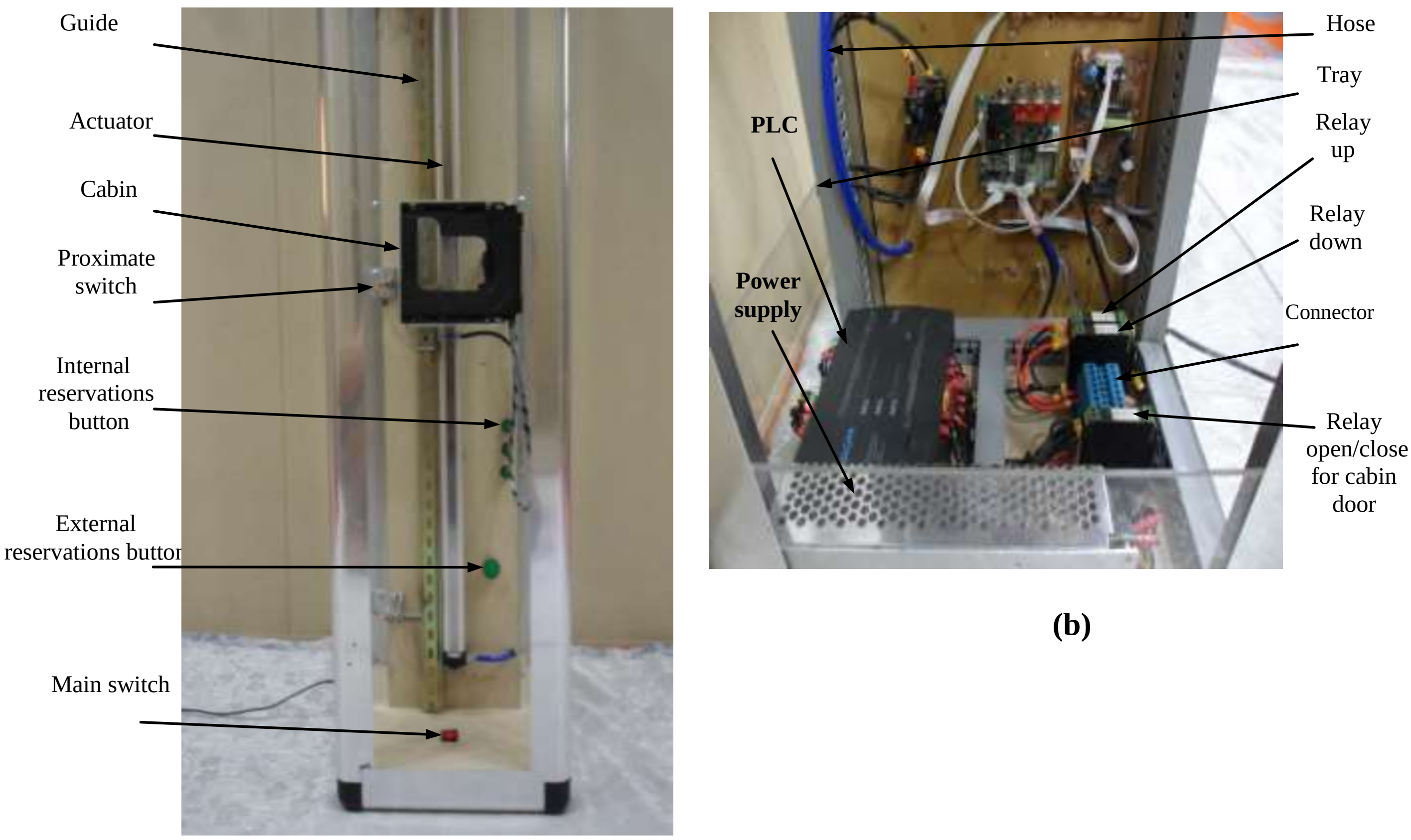


Fig. (1): Block diagram of the electro-pneumatic elevator



(a) (b)

Fig. (2) : Elevator system (a) front view (b) back view

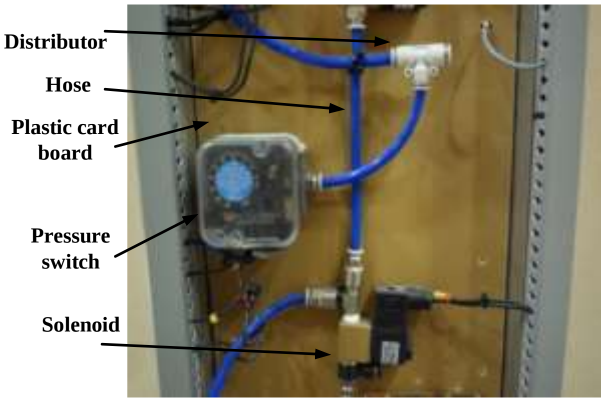


Fig. (3) : the back view; solenoid

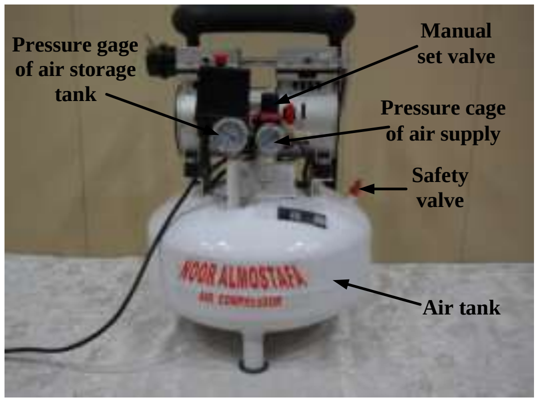


Fig. (4) : the air compressor

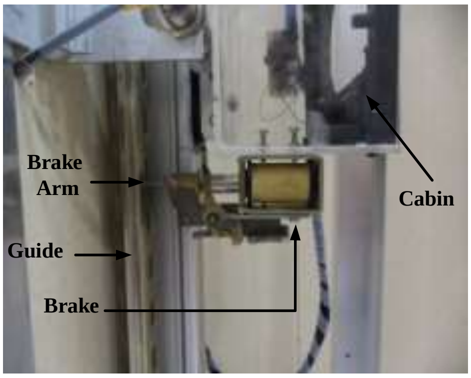


Fig. (5): The Cabin brake

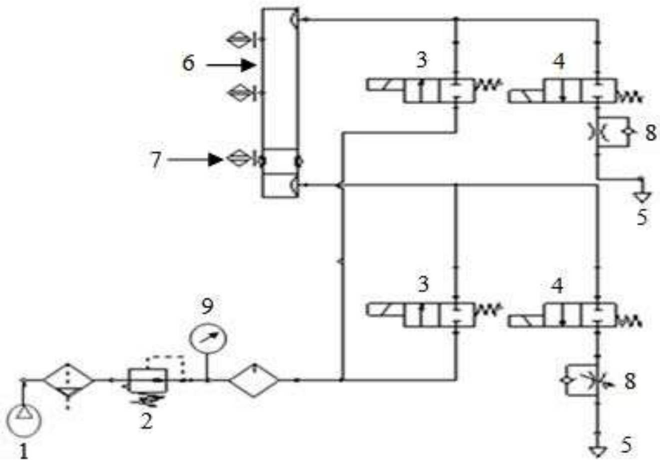


Fig. (6): Elevator Pneumatic Schematic Diagram

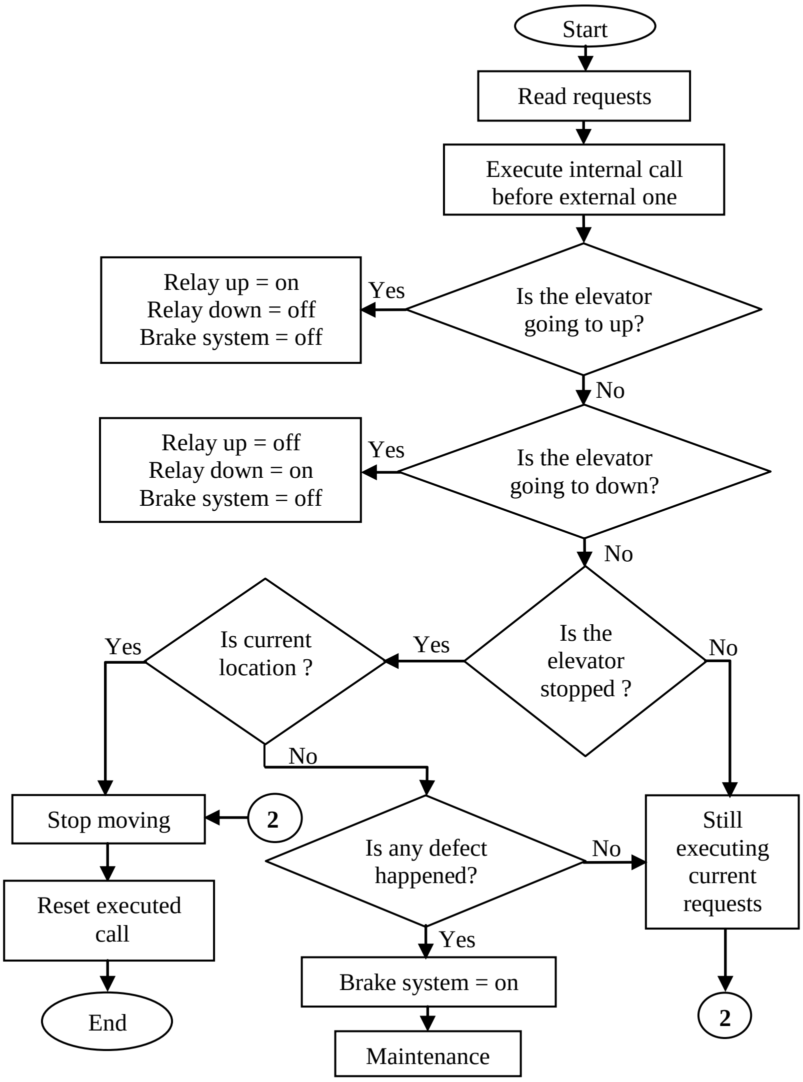


Fig. (7): Elevator control algorithm flowchart

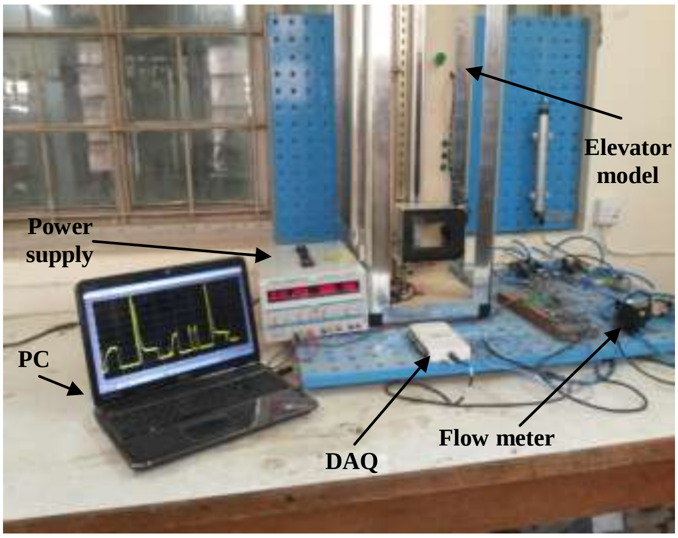


Fig. (8): the Experimental Setup

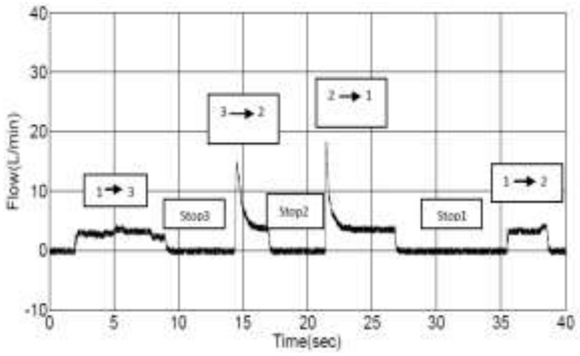


Fig. (9): No-load flow curve; floor level pattern (1→3→2→1→2)

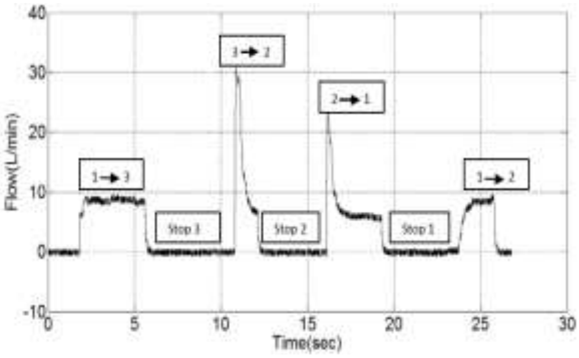


Fig. (10): flow curve at 2kg payload; floor level pattern (1→3→2→1→2)

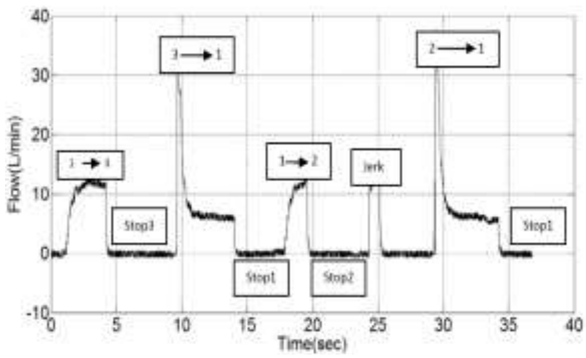


Fig. (11) : flow curve at 5kg payload, floor level pattern (1→3→1→2→1)

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