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APPLICATION A POSITION CONTROLLER MODEL OF THE PNEUMATIC ACTUATOR BASED ON ELECTROMECHANICAL SENSORS

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ABSTRACT

This research paper is concerned with study the performance of a position control model of the rod in double acting pneumatic cylinder using economic process and simple electric control circuit. The proposed model involves two electromechanical sensors to determine the stroke of the pneumatic actuator that steering by two solenoid valves and electrical control subsystem conducted to limit switches to stop the rod at the required position and to achieve the position control system. A comparison is made between the experimental and theoretical results to investigate the better behavior of the suggested model.

Keywords: *Pneumatic system, electromechanical sensors, controller model.*

I. INTRODUCTION

Pneumatic systems are extensively used in the automation of production machinery and in the field of different automatic controller models with relatively high force output-to-weight ratios, comparatively cleanliness and low cost. The word Pneumatic derived from the Greek word, pneuma meaning breeze or breath and it is generally classified as the study of the air processes to give a name to the science of the motions and properties of air [1] & [2].Pneumatic systems are well suited for a number of industrially relevant tasks ranging from point-to-point positioning to high-accuracy servo positioning and force control and they are widely implemented in different industrial applications in which the pneumatic actuators play an important role and offer several advantages for positioning applications actuators is the position control of robotic manipulators, end effectors, and grippers, where stiff and lightweight structures are critical [2]&[3]. In comparison with hydraulic system, pneumatic actuators are safe and reliable to be used in term of environmental contaminations as well as personnel protection [4].

In this work an integration of electrical and pneumatics components with compressed air source is employed in the suggested electro-pneumatic position control system .The proposed electro-pneumatic position controller model consists of electrical control systems, pneumatic actuator, solenoid valves in addition to electromechanical switches that represent an actuator which mechanically linked to a set of electrical contacts to produce a limit position sensors. The pneumatic system contains air compressor unit producing required amount of linear energy, as well as hoses and other accessories. Actuation of the pneumatic cylinder is carried out via DC solenoid valve energized from electrical energy source with rated voltage equal to 24V.

This paper is organized as following; the description of the employed pneumatic apparatus has been introduced in the second section while the detailed of the position controller model and the results of the experimental work are presented in the third and fourth sections respectively followed by conclusion.

II. ElECTRO- PNEMUTIC SYSTEM

The proposed electro pneumatic circuit diagram, along with the components used and their assembly, is shown in Figure (1). The pneumatic system contains the double solenoid valve used as interface between the electrical and pneumatic systems, the pneumatic cylinder driven with compressed air supplied from the air compressor unit, and electrical control board. The apparatus of this system and the characteristics of the electro pneumatic components with detailed physical features of the components are listed as shown in the table (1).

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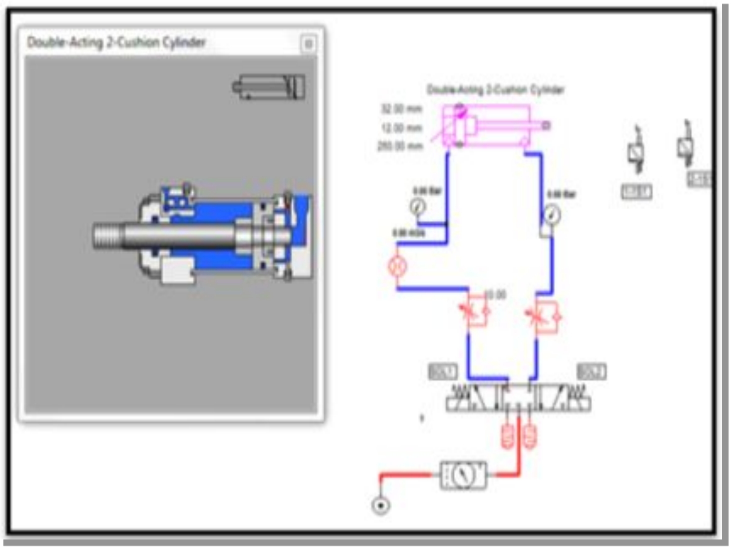


Figure 1: the Schematic Diagram of the Suggested Electro Pneumatic System.

As soon as the solenoid is being electrically energized the rod of the cylinder will be moved either to the left or to the right direction depends on which solenoid has been actuated. The limit switches will stop the rod at the set point previously determined according to the required position.

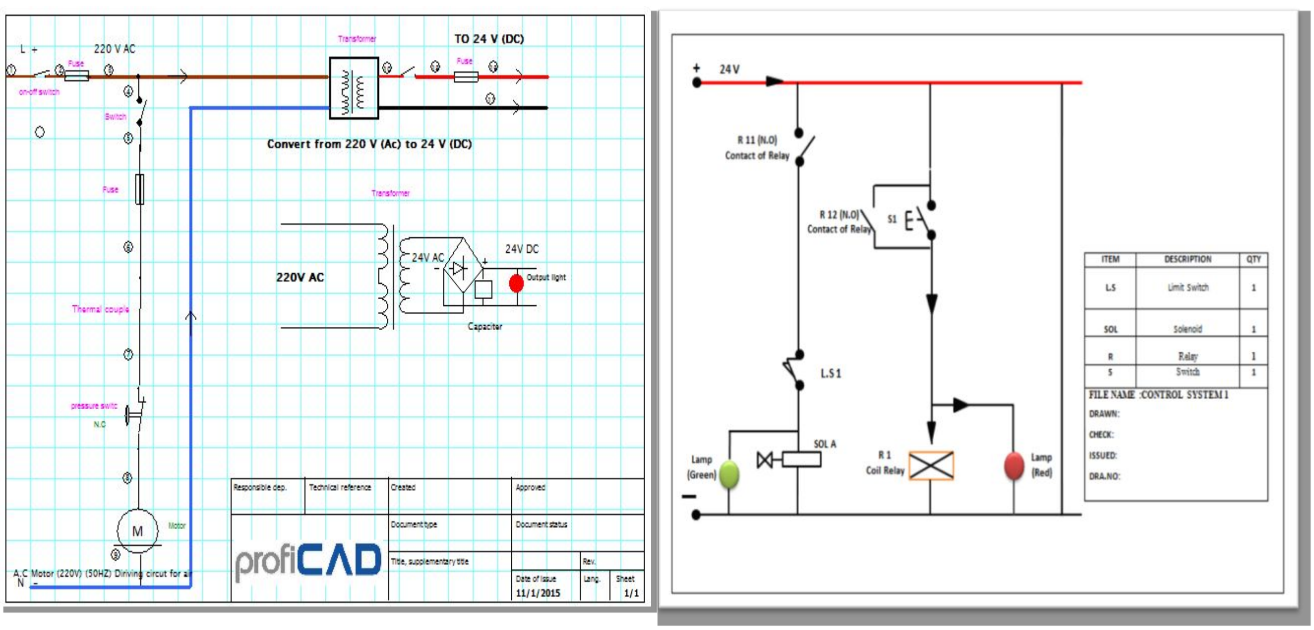
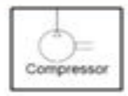
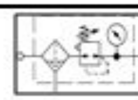
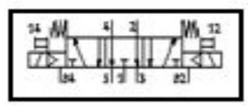
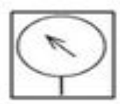
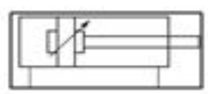
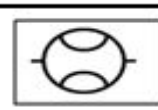


Figure 2: the Schematic Diagram of the Electric Control Circuit.

The electrical control circuit contains, DC power supply, solenoid coil, relays, switches and electromechanical sensor as shown in figure (2).it involves protection circuit, provisions and safety features for manual controls.

Protections circuit includes devices like over load protection and fuses, safety features includes fault indicators alarms (light indicator), emergency stop button.

Table (1) the Characteristics of the Employed Electro Pneumatic Components.

Item	Description	Symbol
Air compressor	(110 L/Min), (50) L, 0.8 Mpa	
F.R.L unit	Max 10 (bar)	
Mini limit switch	5A, 250V.AC, 4A ,115V.DC 2 NC,2NO	
Electromagnetics solenoid valve with Double Coil (Mid close)	5/3 - 5 Ported, 4 Way, 3 Position Valves, Piloted, G 1/8,24V DC.	
Pressure Gauge	Max (10 bar),1 Mpa	
Pneumatic cylinder Double acting	Max pressure (12bar) Bore size (32 mm) Stroke length (250mm) PPV-A	
Flow rate meter	20 L/min	

III. POSITION CONTROLLER

In the proposed controller model, the electromechanical sensors are primarily used to stop the piston of the cylinder and send a feedback signal to the control circuit as soon as the rod of the piston comes into contact with the sensors as shown in figure (3). Basically they will operate to make breaking of an electrical connection and cut off the electrical energy supplied to the solenoid valve and consequently the rod of the cylinder will stop at the required position. According to the control requirements, the stroke of the piston rod are determined by (20 cm)

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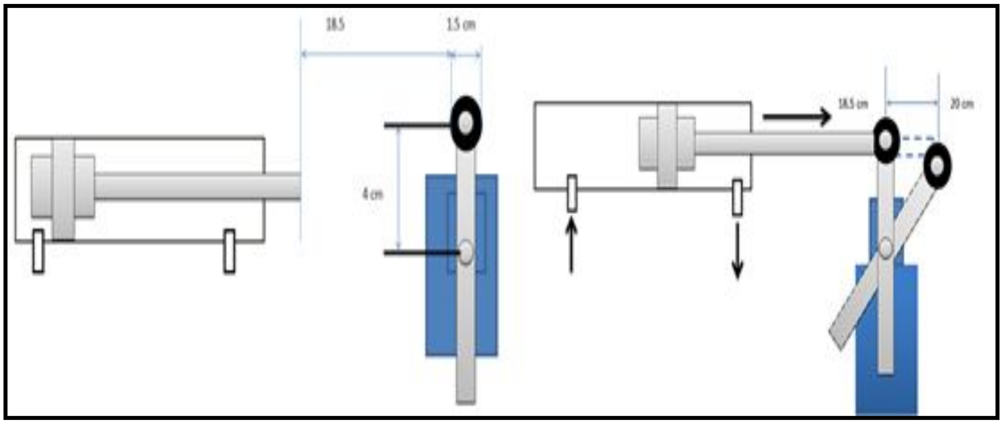

Figure 3: the Limit switches and Pneumatic Actuator.

The control process can be summarized as following; when the solenoid coil actuated the flow of the compressor air will be passed toward the pneumatic cylinder and the piston of the cylinder will be moved toward to the right direction until it reaches the limit switch (LS2) which is electrically connected in series combination with solenoid coil. The electrical contacts of the Limit switch is set as normal closed (N.C) position in order to stop the piston of cylinder and de-energized the solenoid coil.

IV. THE EXPERIMENTAL WORK AND RESULTS

In general, the control of the pneumatic piston cylinder is controlled by a flow-control solenoid valve which is electrically energized by suitable power source. The construction of the system with devices is depicted as shown in figure (4).

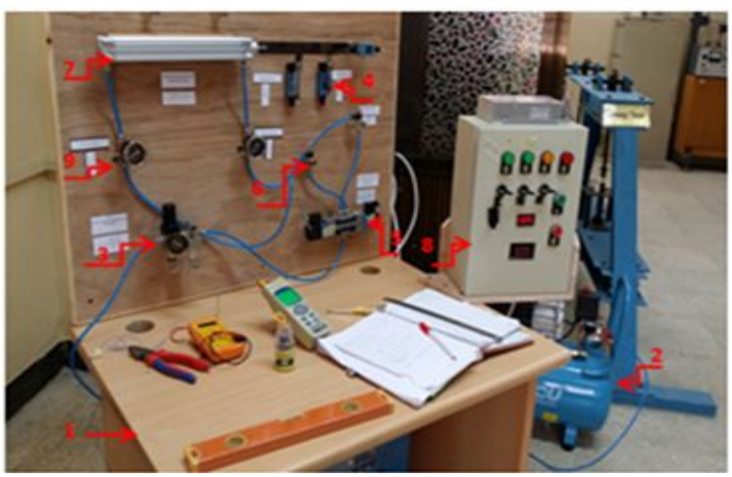

Figure 4: the Employed Electro Pneumatic Position System.

The mathematical calculations In term of the adjustment of the charging or discharging flow when using the flow-control valve will be done as following:-

Experimentally and According to the characteristics of the selective pneumatic cylinder (D (Diameter of piston) =32 mm ,d (Piston rod diameter) = 12 mm, L (Stroke length) =250 mm).the theoretical air consumption calculations of a pneumatic cylinder will be [5]:

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Free air consumption in liters for forward stroke

$$C_{cons} = \frac{[\pi/4 * D^2 * (P+1) * L]}{1000} = 0.321\ L \quad \ldots\ldots.. (1)$$

Free air consumption in liters for returned stroke

$$C_{cons} = \frac{[\pi/4 * (D^2 - d^2) * (P+1) * L]}{1000} = 0.276\ L \quad \ldots\ldots. (2)$$

Hence the Total air consumption for one cycle stroke = 0.321+0.276 = 0.597 L

Since the force developed by a cylinder is a function of the piston diameter, the operating pressure and the frictional resistance. For the theoretical force, the thrust on a stationary piston, the friction is neglected. This, theoretical force, is calculated using the formula [5]:

$$\text{Force (N)} = \text{Piston area } (m^2) * \text{Air pressure } (N/m) \quad \ldots\ldots\ldots (3)$$

Where

A= 8.042 * 10-4 m2 Forward piston and force F= 2* 105 * A = 160.8 N

Arod = 6.911 * 10-4 m2 Return piston and force F= 1* 105 * Ar = 69.11 N

The flow rate and velocity in pneumatic cylinder are calculated using the formula [4]:

$$\dot{V} = A * V \ldots\ldots\ldots.. (4)$$

$$\dot{m} = \dot{V} * \rho \quad \ldots\ldots\ldots (5)$$

$$m\ddot{x} + c\dot{x} = \Delta F \quad \ldots. (6)$$

where
V: Flow rate (m3/s)
M: mass flow rate (Kg/s)
A: effective area of piston (m2)
ρ : density of air =1.21 kg/m3
m:mass of the piston cylinder (kg)=0.526 kg
c:damping coefficient (N.s/m)=100 N.s/m

The results data can be listed as shown in table (2).

Table 2.

The Results from Measuring the Flow Rate and the Amount of the Movement Distances of the Roller Lever

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Flow rate (L/min)	Flow rate(m3/min)	Mass flow rate(g/min)	Velocity of piston(m/s)	Distance (cm)	Distance (m)	Time (s)
0	0	0	0	0	0	0
4.5	0.0045	5.266	0.093	20	0.2	3
6	0.006	7.021	0.12	20	0.2	2
7	0.007	8.191	0.145	20	0.2	1.4
8	0.008	9.361	0.165	20	0.2	1.2
10	0.01	11.7	0.207	20	0.2	0.96
11	0.011	12.8	0.228	20	0.2	0.87
12	0.012	14.04	0.248	20	0.2	0.81
15	0.015	17.55	0.311	20.5	0.205	0.66
16	0.016	18.72	0.33	20.5	0.205	0.62
17	0.017	19.89	0.35	20.5	0.205	0.58
18	0.018	21.06	0.37	21	0.21	0.56
19	0.019	22.23	0.4	21	0.21	0.5

The relation between the velocity of piston cylinder and flow rate can be plotted as shown in figure (5) and It can be seen that the velocity become quickly with increase flow rate according to equation (4). The stop point of the rod of the pneumatic actuator is depended on the limit switch, the roller level of the limit switch is varied according to the flow rate of the compressed air, The relation between flow rate ,velocity of piston cylinder and displacement of are plotted as has shown in Figure (6) and figure(7) respectively. It can be seen that the displacement of roller level becomes constant from value of flow rate about (4.5 l/min to 12 l/min), while if the flow rate increased above (12 l/min) the displacement of the roller level of the limit switch will be changed and became constant at flow rate equal to (17 l/min).when the flow rate increased above (17 l/min), there is no change in the set point value. The measurement of the flow rate was carried out using flow control valve and flow meter device.

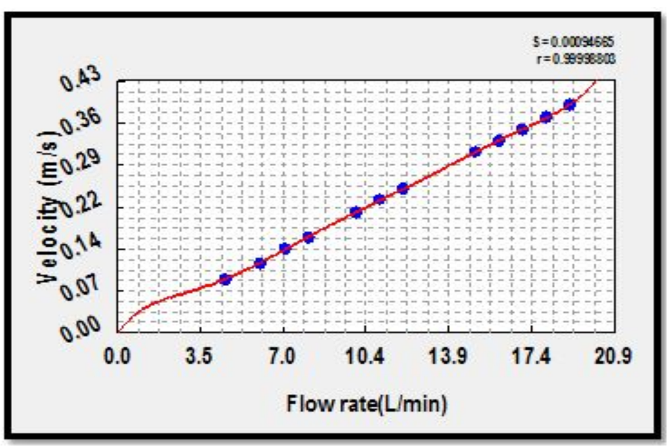

Figure 5: the Velocity of the Piston versus the Flow Rate.

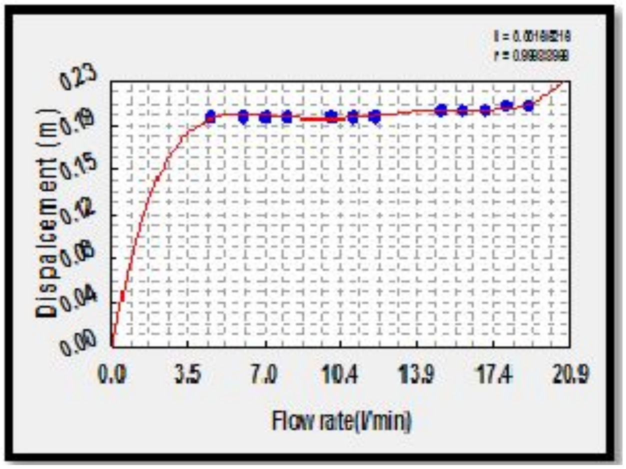

Figure 6: the Piston Displacement versus the Flow Rate.

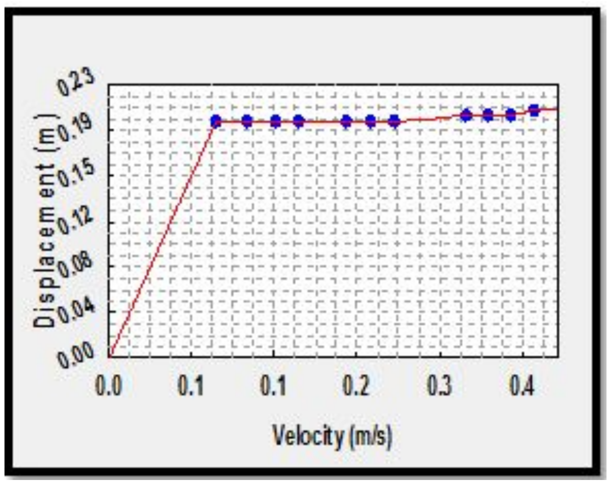

Figure 7: the Limit Switch Displacement versus Velocity of the Piston

The relation between the obtained data and the time required to reach the set point (20 cm) throughout practical experimental in the lab can be displayed as shown in figure (8).

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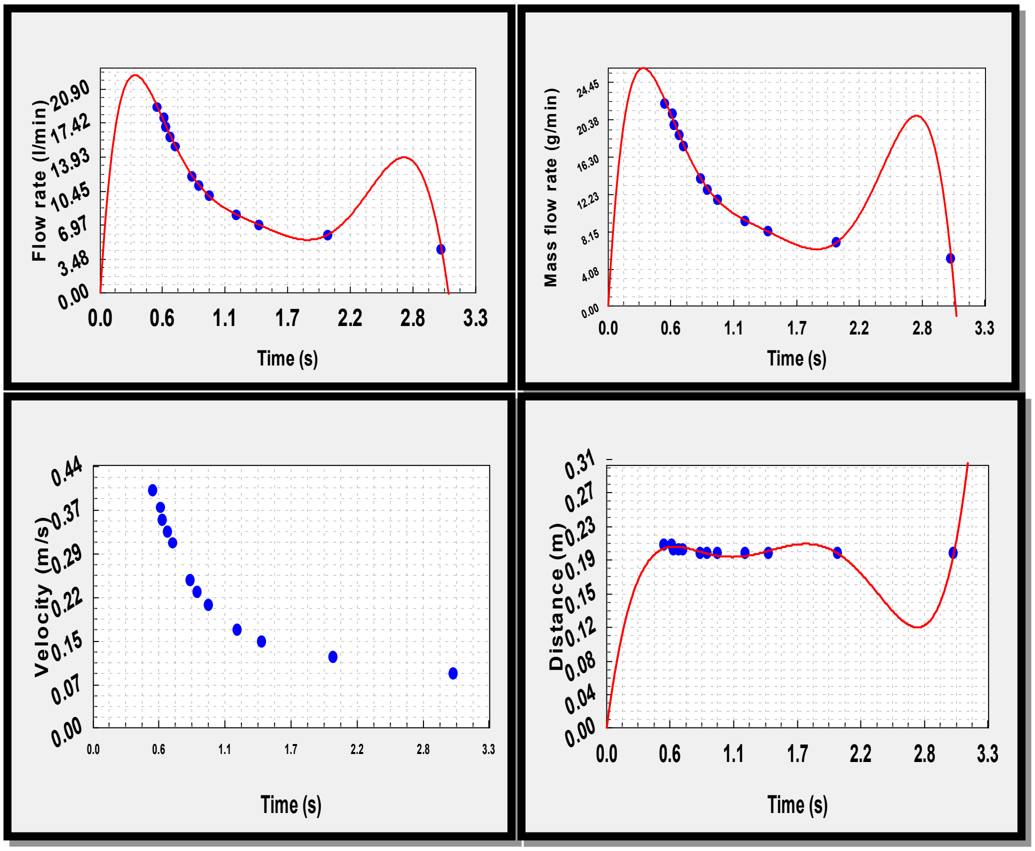

Figure 8: the Experimental Results versus Time.

The mathematically calculation of the shifting in the position of the roller lever for the limit switch, at the moment when the rod of the cylinder mechanically touched the limit switch as shown in figure (8), can be obtained as the following-

$$A^2 + B^2 = C^2 \quad \ldots\ldots. (7)$$

$$4^2 + 1.5^2 = C^2 \quad \text{Leading to} \quad C = 4.272 \text{ cm}$$

And the angle between the confined installation point and a point of the second movement:

$$\Theta = \tan^{-1}(B/A) = 20.55^{\circ} \quad \ldots\ldots (8)$$

It can be noticed that any increasing in the flow rate of the gas above (12 L/min) result in the stop position according to the set point that previously determined will be varied between (20.5cm, 21cm), as and the deviation angle will be varied between (26.56°, 32°).

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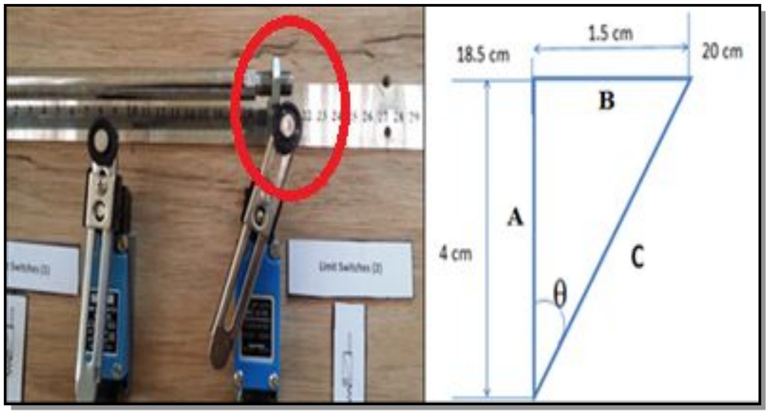

Figure 8: **the Stop Position of the Limit Switch.**

V. CONCLUSION

In this work, a controller model of the position for the pneumatic actuator implemented electromechanical sensors has been carried out. According to the experimental results it can be concluded that

1- The pneumatic system is preferred when the system required high speed, medium pressure and less accuracy of position.
2- The gas in a pneumatic system behaves like a spring since it is compressible and to obtain the optimal control in a pneumatic driven system is not easy process.
3- Electro-mechanical Limit switches are used in a variety of industrial applications and environments because of their ruggedness, ease of installation, and reliability of operation.
4- It can be used very précised sensors to obtain high accuracy in the position control model in order to avoid any drawbacks in the experimental results.

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