Application of Directional Control Solenoid Valves in Pneumatic Position System

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Abstract. This paper focuses on the ability of application of electro pneumatic position control system based on, double acting pneumatic cylinder actuating by directional control solenoids valves and linked with position sensor. The suggested approach involved practical and theoretical work to realize an efficient pneumatic control system employed conventional solenoid valves instead of proportional or servo valves. It has required to set up a test rig contains the recommended electrical and pneumatic apparatus and involved the mathematical calculations as well as the computer simulation. A compare between practical and theoretical results have been carrying out to investigate the rendering of the suggested position control system including the position sensor. The obtained results showed that it can be used the directional control solenoid valve instead of other types of pneumatic valves such as proportional or servo solenoid valves with acceptable response and achieved position control system with high accuracy.

Keyword: Pneumatic actuator, solenoid valve, position sensor, simulation.

1. Introduction
In general, the electro pneumatic components have been founded in several engineering applications in the industrial field in order to achieve control system such as automation circuit and different application [1-3]. Much of these enforcements are lead in the fields of the low-cost system because of the traditional of the pneumatic equipment and their related electrical parts are more conceived to work with on/off conduction states. Pneumatic has become an important driving element that extensively using in robotics design and automated process to produce rectilinear or rotary direction and to offer a good alternative to electrical or hydraulic control systems for specific typing of applications for the purposes of clean environments, safety system and easier to work. In particular, the development of the electro-pneumatics had been due to the evaluation of the electronics, which has given a wide range of solutions in terms of sensors, controller’s parts with various mechatronic devices[3-6]. Moreover, the electro-pneumatics is not working in two states, but several analogue and digital components can be found. The mean part which can be used in this research is the directional control solenoid valve. In fact; solenoid control valves play an important role are in all fluid power systems. They can be classified by their function such as directional control valves for directing flow of fluid to one or the other side or flow control valves for limiting the flow rate of the fluid in a the applied pneumatic or hydraulic systems. Valves are also characterized by kinds of their manufacturing either to conventional directional solenoid control valves or proportional as well as servo valves. Practically the conventional directional control solenoid valves or they can be described as On/off valves which can be only operated in one state while the proportional valves could take on any position in the employed working range. A servo valves is a specific type of proportional valves which has an internal closed-loop feedback mechanism to gain a precise control systems[2-8]. There are several ways to achieve an appropriate control model of pneumatic system to gain the typical response of a system beside its stability and sensitivity to the
parameter changes, it can be considered the mathematical Modeling of dynamic system as necessary step in engineering task and represent the means that permit some guidelines rules in the computer simulation process. Building the simulation model provide an opportunity to find out the effect of component parameters which influences in the employed control system[5-10]. The main objectives of this research are to design with implementation of a position controller model of electro pneumatic system based on directional control solenoid valve. To achieve this purpose; it has been designed and used an electromechanically circuit involved linear position sensors linked with pneumatic cylinder and driven by electronic control circuit to energize the coil of the solenoid valve with rated power according to the feedback signal. Therefore, it has built a laboratory model rig contains the electro-pneumatic devices and the position sensor to realize the position control action of the double acting cylinder. Computer simulation of the employed system involving the mathematical model had been done to investigate the better performance of the position system.

This paper is organized as following; the description of the electro-pneumatic system had been introduced in the second section while the details of the position controller model with the results of the experimental beside simulation work are presented in the third and fourth sections respectively followed by conclusion.

2. The Electro Pneumatic position control system
The main parts of the proposed pneumatic position control system are double acting cylinder, directional control valve with DC solenoid coil, position sensor, electrical circuit and air power unit. these equipment has been arranged as shown in Figure 1.

![Figure 1. The Layout of the Pneumatic Position Control System](image)

Pneumatic actuators such as pneumatic cylinder could be defined as an output device which has been use for conversation the input supply energy into output useful work and provide rectilinear motion[6]. Solenoid valves represent the basic element of the pneumatic system; they are responsible for actuating the pneumatic cylinder in the required direction according to the incoming electrical signal to the coil of the solenoid. Another important part in the pneumatic control system is the linear position sensor. It has been used to convert the rectilinear movement of the pneumatic cylinder into corresponding electrical signal.

3. The Suggested Electromechanical Circuit
In order to install an alternative of the proportional solenoid valve, it was needed to use a specific type of electromechanical transducers which detect the linear displacement in the position of the cylinder rod with a high precision with send a feedback electrical signal to the control unit[10]. It has been
mounted in a horizontal position with mechanically linking in parallel with the pneumatic cylinder as shown in Figure 2. This mechanism was done to ensure that the sensor part will detect the linear motion of the cylinder rod and electrically interfacing with position controller unit.

The employed position sensor can be considered as a variable resistance which produces a different output value of resistance proportional to the displacement of the cylinder rod. When the sensor rod moves in either right or left direction it will because the changing in the value of the electrical signal which transmitted to electronic control circuit. The design of the electronic control circuit card has been set up with taking into account the requirement of the position control system as shown in Figure 3.

The main part of the electronic control unit is the comparator elements that contains of four independent operational amplifiers shown in Figure 4.
Figure 4. The diagram of Position Sensor Control Circuit

The required reference voltage for the controller unit in above Figure 4 has been set using the variable resistance with rotating contact that produce an adjustable values of voltage signal which supplied to the electrical circuit designed to divide these voltage to the maintain value. The specific setting value of the voltages is directly proportional to the corresponding value movement distance of the cylinder rod which is mechanical linked to the position sensor.

To ensuring that the position sensor is working properly, the test and calibration process of the employed sensor was done in the electronic laboratory /electrical department, faculty of engineering. The calibration processes were including the simulation of the motion of the sensor in the different values of signals.

The supplying voltage energized from the power source to the calibration circuit has been varied from 0 V level to 19 V level and the obtaining results are measured practically using the digital devices such as multimeter and power supply with using the oscilloscope device to display the results as shown in Figure 5.

Figure 5. The Calibration Circuit of the linear position sensor

The supply voltage is 19 V and it is applied to the linear position sensor that acts as a variable resistance with the value is equal to 5.14 kΩ. The results of the simulation of the calibration proportional linear position sensor obtaining by using the electronic software can be listed as shown in table (1).
Table 1. Rod Position of sensor Versus Voltage (Calibrations Results with resistance of sensor 5.3 KΩ and input voltage Vin=24)

| Rod distance (cm) | Resistance (KΩ) | V(output voltage) (µ V) |
|-------------------|----------------|------------------------|
| 0                 | 0.39           | 936.6                  |
| 2                 | 0.66           | 208.4                  |
| 4                 | 1.03           | 218.7                  |
| 6                 | 1.38           | 223.8                  |
| 8                 | 1.72           | 226.8                  |
| 10                | 2.14           | 229.3                  |
| 12                | 2.46           | 230.6                  |
| 14                | 2.8            | 231.7                  |
| 16                | 3.17           | 232.6                  |
| 18                | 3.55           | 233.4                  |
| 20                | 3.86           | 233.9                  |
| 22                | 4.20           | 234.4                  |
| 24                | 4.58           | 234.8                  |
| 26                | 4.89           | 235.2                  |
| 28                | 5.27           | 235.5                  |
| 30                | 5.56           | 235.7                  |

The calibration process has been done in the electronic lab at the Electrical Engineering department to testify the electronic card of the controller unit and to compare the practical results with theoretical test as shown in Figure 6.

Figure 6. Electrical wired Connections of the Controller Card

4. Results of the Position Controller based on the Proportional Position Sensor
The experimental work deals with ability of employing the proportional linear circuit of the position sensor to actuate the solenoid valve interfacing with proportional controller unit. The procedure was done with the same values of the air flow rate that had been used in the position controller based on the limit switch sensor and implemented in order to check the difference between the two controller models. The obtained experimental results of the position controller card based on linear position sensor are listed as shown in table (2). The practical results also include the corresponding values of speed for the cylinder rod.

The experimental results of the electro-pneumatic position system using proportional position sensor would be plotted as shown in Figure 7.
Table 2. The Results of the Calibration Test with the Simulation Results (Practically)

| Position (cm) | Practical Voltage (V) | Simulation Voltage (V) | Error % |
|---------------|------------------------|------------------------|---------|
| 0             | 0                      | 0                      | 0       |
| 1             | 1.3                    | 1.43                   | 9       |
| 5             | 3.35                   | 3.57                   | 6.16    |
| 7             | 4.63                   | 4.82                   | 3.94    |
| 10            | 6.31                   | 6.64                   | 4.96    |
| 13            | 8.52                   | 8.65                   | 1.5     |
| 15            | 9.27                   | 9.99                   | 7.2     |
| 16            | 10.66                  | 10.86                  | 1.84    |
| 19            | 12.04                  | 12.22                  | 1.4     |
| 20            | 12.24                  | 12.8                   | 4.3     |
| 25            | 16.12                  | 16.6                   | 2.86    |

Figure 7. Input Setting Voltages versus Outputs the rod position of the Sensor

Hence, the transfer functions of the pneumatic double acting cylinder can be as expressing as in equation (1) under assumption that the air inside the cylinder would be an ideal gas, with the pressures of atmosphere and air source are constant and there is no leakage of the cylinder: [8,9]

\[
\frac{y_{out}(s)}{x_{sp}(s)} = \frac{Q}{s\left(\frac{1}{w_n^2} + \frac{2\zeta}{w_n} + 1\right)} \tag{1}
\]

\[
Q = \frac{C_x}{A_p} \tag{2}
\]

Where:
- \(C_x\) = Flow coefficient
- \(A_p\) = Piston area
- \(\zeta\) = damping ratio
- \(w_n\) = natural frequency

However, the transfer function of the pneumatic double acting cylinder can be plotted in the block diagram as shown in Figure 8

Figure 8. The Transfer Function of the Pneumatic Cylinder

Where \(Y_{out}\) represents the output position of the cylinder rod and \(x_{sp}\) is the spool displacement of the control valve.
The directional double solenoid valve model that had been employed can be depicted as shown in Figure 9.

![Figure 9. The Schematic layout of the Directional Control Valve](image)

It could be subdivided into three parts; the electrical, Mechanical and electromagnetic subsystem parts. The electrical involves the current passing through the coil that producing the corresponding magnetic field within the valve. The producing magnetic field was causing to move the spool into the required direction. So the solenoid valve is used to control the air flow through the valve orifice in order to control the rectilinear motion of the cylinder[10, 11].

The transfer function of the electrical subsystems is

\[
\frac{1}{Ls+R} \quad \text{And} \quad x_L = 2\pi fL, \text{where } f=\text{frequency}
\]  

(3)

The transfer function of the directional control valve = \[\frac{k_{\text{coil}}}{ms^2 + cs + k}\]

The block diagram of the transfer function of motion for the valve spool would be plotted as shown in Figure 10.[12]

![Figure 10. The Transfer Function of the Solenoid Valve](image)

The simulation model of the electro position control system including the transfer functions was done in Matlab/Simulink as shown in Figure 11 with using the proportional controller model and the position sensor (linear type) with different set points.[13]
The flow rate values will be start from zero value at the beginning of actuating the directional control valve until reaching the desired value of flow which is equal to 17 l/min and stop point of the cylinder rod at (10 cm). This value of air flow rate was controlled through air throttle valve which connected in pneumatic circuit to control the flow rate. As the feedback signal reaches to the controller card from the position sensor, it would be compared with the set point that it represented the specified distance required for stopping the rod of cylinder. So, if the feedbacks signal is equal to the set value then the controller unit will cut off the electrical signal that reach to the solenoid valve and lead to stop the cylinder rod at the set point. The controller unit will be also responsible to return the rod of the cylinder in the backward direction to its original position. The simulation of the proportional controller unit was done including the mathematical models of the system as shown in Figure 11, it has been depended on several parameters such as the value of the resistance of the solenoid coil part, the damping coefficient of the solenoid, the force coefficient of the coil as well as the gain factors of the proportional controller. The process of simulation of the Simulink model of the electro pneumatic position control system in Matlab software package will be started with set point determined as (10cm) and air rate flow equal to (6 l/min) and then repeated with air rate flow equal to 15 l/min. The response results of the control system were displayed as shown in Figures 12 & 13.[14]
Change the set point from (10cm) to (20cm) and air rate flow equal to (6 l/min) and then repeated with air rate flow equal to 15 l/min. The response results of the control system are displayed as shown in Figures 14 & 15.

![Figure 14. The Response of the System at Flow Rate 10 l/min](image1)

![Figure 15. The Response of the System at Flow Rate 15 l/min](image2)

5. Conclusions

It can be noticed that the proposed Simulink model of the proportional controller based on the proportional linear position sensor provide an ability to select any choosing set point of the cylinder rod. It can done to test the flexibility of the position controller model with linear position sensor.

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