© 2017 IJSRST | Volume 3 | Issue 1 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

Accurate Position Control of Pneumatic Actuator Using On/Off Solenoid Valve

D. Venkatesa Prabu#1, A. Sathishkumar#2, C. Manibalaji#3, T. Sakthivel#4, V. Robin#5

[#1,2]Assistant Professor, Department of Mechatronics Engineering, Mahendra College of Engineering, Salem, Tamilnadu, India
[#3,4,5]UG Scholar, Department of Mechatronics Engineering, Mahendra College of Engineering,Salem,Tamilnadu, India

ABSTRACT

paper deals with accurate positioning of pneumatic actuator using solenoid controller to development a fast, accurate, and inexpensive position-controlled that may be applied to a variety of practical positioning applications are described. A Pulse Width Modulation PWM valve pulsing algorithm to allow the on/off solenoid valves to use in the place of costly servo valve. The open-loop characteristic is shown both theoretically and experimentally in near the symmetrical. A comparison of the open- and closed-loop responses of standard PWM techniques and that the PWM technique shows there has been a significant improvement in control. A linear process model is obtained from experimental data using system identification. A intelligent controller of proportional integrative PI controller with position feed forward. A state feedback controller with position, velocity and acceleration feedback as a continuous controller. Proportional integral derivative PID controller with added friction compensation and position controlled pneumatic actuator using Pulse Width Modulation PWM valve pulsing algorithms are described. The system consists a standard double acting cylinder controlled with two three-way solenoid valves through a 12-bit A/D PC board. It is using a non-linear motion of pneumatic actuator to control the plunger positioning it can be analyzed through the displacement or potentiometer sensor.

Keywords: PWM, PID Controller, SMC, VAC, LVQNN, MPWM, FRL

I. INTRODUCTION

A Cylinder and Cartesian robots require linear position control of their actuators to perform their task. Pneumatic actuators offer several advantages for positioning applications as low cost, high power to weight ratio, ease to maintenance & cleanliness. So there is particularly well suited for those applications where speed and lightweight are critical. Unfortunately pneumatic actuators are subject to high friction forces, dead band due and dead time due to the compressibility of the air. These non-line arities make accurate position control for a pneumatic actuator is difficult to achieve. As a result, a considerable amount of research work has been devoted the development in various position control systems for pneumatic actuators and use expansive proportional servo valves and pressure sensor feedback loops. The particularity of this application is that, differently from previous works, there is not a mathematical system model to tune the controller parameters the tuning is made on field using a experimental tuning procedure. The results obtained using this position control system are satisfactory and show a low value for position error and rise time without the necessity of realizing complex non-linear mode. As a result, a considerable amount of research has been devoted to the development of various position control systems in pneumatic actuators. Many of systems, thought successful, use expensive proportional servo valves and pressure sensor feedback loops and the external loads are also assumed to be constant or slowly varying.

II. METHODS AND MATERIAL

A. Pressure Relief Valve

The pressure relief valve (PRV) is used to control or limit the pressure in a system or vessel which can build up for a process upset, instrument or equipment is failure. The pressure is relieved by allowing the pressurized fluid flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined protect pressure vessels and other equipment from being subjected that exceed their design limits. When the set pressure is exceeded, the relief valve becomes the path of least resistance as the valve is forced open and a portion fluid is diverted through the auxiliary route the pressure inside the vessel will stop rising. Once it reaches the valve reseating pressure valve will close. The blow down is usually stated as a percentage of pressure and refers to how much pressure needs to drop before the valve reseats. The blow down can vary from roughly 2–20%, and some valves are adjustable blow downs.

In high-pressure gas systems, is recommended the outlet of the relief valve is open air. In systems where the outlet is connected in piping, the opening relief valve will give a pressure build up in the piping system and downstream of the relief valve. This often means that relief valve will not re-seat once the set pressure is reached. For systems are called "differential" relief valves are used. This means the pressure is only working on area that is much smaller than the opening area of the valve. If valve is opened and the pressure has to decrease enormously before the valve closes the outlet pressure of valve can easily keep the valve open. Another consideration that if relief valves are connected to the outlet pipe system, they may open as the pressure in exhaust.

B. Double Acting Cylinder

A double-acting cylinder is an working the fluid acts are alternately on both sides of the piston is shown in Fig 1.2.

In order to connect the piston in a double-acting cylinder an external mechanism, such as a crank shaft, hole must be provided in one end of the cylinder for the piston rod and this is fitted with a gland or 'stuffing box' to prevent escape of the working fuid.

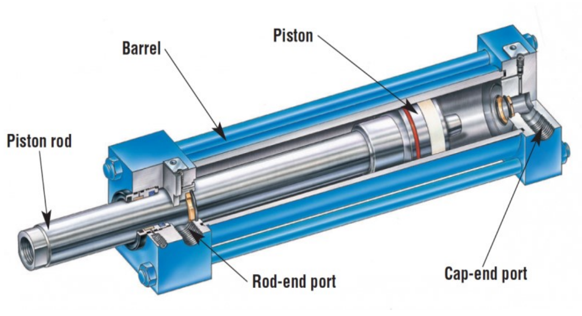

Figure 1. Double Acting Cylinder

Double-acting cylinders are common in steam engines but unusual in other engine types. Many hydraulic and pneumatic cylinders use them needed to produce a force are both directions. A double-acting hydraulic cylinder port at each end, supplied with hydraulic fluid for both retraction and extension of the piston. A double-acting cylinder is used an external force is not available to retract the piston or where high force is required in both directions of travel.

C. PID Controller

A proportional integral derivative controller. The PID controller is a control loop feedback mechanism controller commonly used in industrial control systems. A PID controller continuously calculates the error value as difference between a desired set point and measured process variable. The controller attempts to minimize the error over time by adjustment of a control variable, such as position of control valve and damper or the power supplied to a heating element, to a new value determined by a weighted sum.

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$

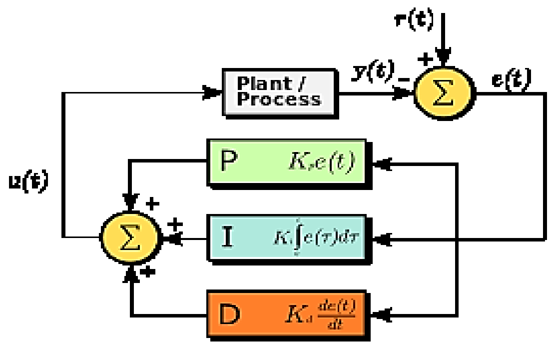

Figure 2. PID Controller

Where Kp, Ki, Kd all non-negative, denote the coefficients for a proportional, integral, and derivative terms, respectively sometimes denoted P, I, and D is shown in Fig 1.3. As PID controller relies only on the measured process variable are not an knowledge of the underlying process, it has broadly applicable. By tuning the three parameters of the model, a PID controller can deal with specific process requirement. The response of a controller can be described in terms of its responsiveness to an error, the degree to which the system overshoots a set point, and the degree of any system oscillation. The use of PID algorithm does not guarantee optimal control of the system or even its stability.

D. Implementing PID Controller

Intelligent control for an electro-hydraulic actuator such as neural networks was proposed for adaptive control which consists of two BP networks and SMC using recurrent high order sliding mode neural networks.

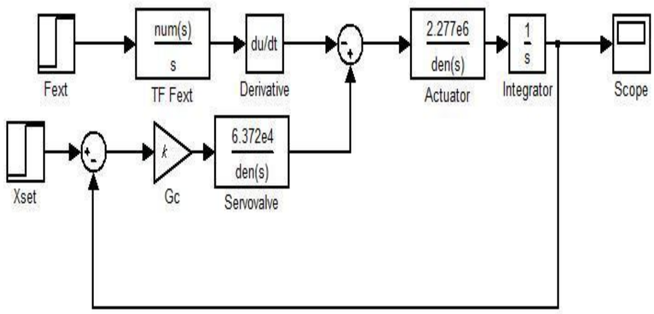

Figure 3. Developing PID Controller

Meanwhile, ANN-based PID control was developed to reach high precision of tracking control of an electro-hydraulic actuator is shown in Fig 1.3 Recently, fuzzy logic control has been actively researched and utilized such as fuzzy-PID controller by combining the merits of fuzzy and conventional, self-tuning fuzzy linear control to improve the robustness and hybrid control of fuzzy and PID, Fuzzy-PD control with stability equation which makes the systems being stable and robust.

E. Implementing PID Controller in Pneumatic Actuator

The PID controller of the two spool type of servo mechanism in two-stage Electro Hydraulic Servo Valve under loaded condition has been develop. The model consist of the interconnection between the Actuator positioning stage, spool dynamics, chamber pressure dynamics, output flow and load dynamics relationship. The model has been implemented using SOLIDWORKS link and Simulation - Pneumatics. The proposed model can be used to predict performance and to provide insights for improving the design of the valve. Improved performances of this relatively in expensive servo valve, either through improve physical design, or through the advance control, can potentially expand the use of electro hydraulics in cost constrained application.

F. FRL Unit

A pneumatic lubricator injects an aerosolized stream of oil into the air line provide lubrication to internal working parts of pneumatic tools, and other devices such as actuating cylinders, valves and motors.

Compressed air enters in the inlet port passes over a needle valve orifice attached to a pick-up tube. This tube - often equipped with a sintered bronze filter - is submerged into the reservoir bowl filled with light machine oil. Oil is pulled up the venturi effect, and emitted as an aerosol at the outlet port. The needle valve is typically situated within a clear polycarbonate or nylon housing to aid the oil flow rate adjustment. Some Compressor oils and external chemicals can cause polycarbonate or nylon sight glass to be degraded and create the safety hazard.

A lubricator should always to be the last element in FRL Filter-Regulator-Lubricator unit. If an FRL is connected "backwards" with incoming air connected to the lubricator, oil-laden air interferes in pressure regulator operation, oil is separated from the air stream and drained by the filter, and very little or none is delivered to connected equipment.

Figure 4. 6 FRL unit

G. ON/OFF Solenoid Valve

There are many valve design variations. The ordinary valves can many ports and fluid paths. A 2-way valve, for example, has 2 ports; if the valve is open, then the two ports are connected to fluid may flow between the ports; if the valve is closed then ports are isolated. If valve is open when the solenoid is not energized, then the valve is termed normally open (N.O.). Similarly, if valve is closed when the solenoid is not energized, then the valve is termed normally closed. There are also 3-way and more complicated designs. A 3-way valve has 3 ports; it connects one port to either the two other ports typically a supply port and an exhaust port. Solenoid valves are also characterized by how they operate. A small solenoid can generate the limited force. If force is sufficient to open and close the valve, then a direct acting solenoid valve is possible. An approximate relationship between the required solenoid force Fs, the fluid pressure P, and the orifice area of direct acting solenoid value. (Fs PA Pπd2)

Where d is the orifice diameter. The typical solenoid force might be 15 N (3.4 lbf). An application might be the low pressure (e.g., 10 psi (69 kPa)) gas with a small orifice diameter (e.g., 3⁄8 in (9.5 mm) for an orifice area of 0.11 in2 (7.1×10−5 m2) and approximate force of 1.1 lbf (4.9 N)).

The solenoid valve is small black box at the top of photo with input air line small green tube used to actuate a larger rack and pinion actuator gray box which controls the water pipe valve. When high pressures and large orifices are encounter, then high force are required. To generate the forces are internally piloted solenoid valve design may be possible. In such a design line pressure is used to generate the high valve forces; a small solenoid controls how the line pressure is used. Internally piloted valves are used in dishwashers and irrigation systems where the fluid is water and pressure might be 80 pounds per square inch (550 kPa) the orifice diameter might be 3⁄4 in (19 mm). In some solenoid valves the solenoid acts directly on the main valve. Others use in a small complete solenoid valve is known as a pilot, to actuate a larger valve. While the second type is actually a solenoid valve combined with pneumatically actuated valve, they are sold and packaged as a single unit referred to the solenoid valve. Piloted valves require much less power to control, but they are noticeably slower. Piloted solenoid usually need full power at all time to open and stay, where the direct acting solenoid may only need full power for a short period of time to open it, and only low power to hold on. A direct acting solenoid valve operates in 5 to 10 milliseconds. The operation time of a pilot valve is depends on its size; typical values are 15 to 150 milliseconds.

Figure 5. ON/OFF Solenoid Valve

The power consumption and supply requirements of solenoid vary with application, being primarily determined by fluid pressure and line diameter. For example, a popular 3/4" 150 psi sprinkler valve, and intended for 24 VAC (50 - 60 Hz) residential systems, has a momentary inrush of 7.2 VA, and a holding power requirement of 4.6 VA. Comparatively, an industrial 1/2" 10000 psi valve is intended for 12, 24, or 120 VAC systems are in high pressure fluid and cryogenic applications, it has an inrush of 300 VA and a holding power of 22 VA. Neither valve lists a minimum pressure required to remain closed in un-powered state.

The solenoid valve is an electromechanically operated valve. The valve is an controlled by electric current through a solenoid: in the case of two-port valve flow is switched on or off; in the case of three-port valve, the outflow is switched between two outlet ports. The multiple solenoid valves can be placed together on a manifold. Solenoid valves are the most frequently used control elements in fluid. The tasks are to shut off, release, and distribute or mix fluids. They are found in many application areas. Solenoids offer fast and safe switching, high reliability or long service life, good medium compatibility of the materials are used. If has low control power and compact design. The plunger-type actuator is used most frequently, pivoted-armature actuators and rocker actuators are also used.

H. Foot Pedal Valve

A pedal from the Latin *pes*, *pedis*, meaning 'foot' is a lever activated by the one's foot, sometimes called a "foot pedal" but all pedals are used by a foot.

1. Transport

Pedals in road vehicles, see Car controls Pedals Bicycle pedal, any set of levers which drive the rotation of a gear train Pedal a small boat, usually used for recreational purposes, powered by pedals Rudder pedals on aircraft, see Rudder &Aircraft rudders, a campaign group in Nottingham, England.

2. Electronic equipment

- Foot pedals are often used to control playback transcribers are used in medical transcription.
- Footmouse, a foot-operated in computer mouse

3. Geometry

- Pedal triangle is obtained by projecting a point onto the sides of a triangle
- Pedal curve is derived by construction from a given curve is used in a pedal bin

Figure 6. Foot Pedal Valve

A sustain pedal or sustaining pedal also called damper pedal, or open pedal is the most commonly used pedal in a modern piano. It is typically to rightmost of two or three pedals. When pressed the sustain pedal damped strings on the piano is moving all the dampers are away from the strings and allowing them to vibrate freely. All the notes played will continue to sound until the vibration naturally ceases, or until pedal is released.

The pianist sustain notes would be out of reach, for instance in accompanying chord and accomplish legato passages smoothly connected notes which have no possible fingering otherwise. Raising the sustain pedal is also causes of all the strings to vibrate sympathetically in whichever notes are being played, which greatly enriches the piano's tone.

A device similar to the sustain pedal effect was invented by the piano pioneer Gottfried Silbermann it has operated by the player's hands rather than a pedal. The later eminent early builder, Johann Andreas Stein, may have been the first to allow the player in lift the dampers while still playing; his device was controlled by a knee lever.

4. Specifying pedalling in musical compositions

Appropriate use of the pedal is often to the musician's discretion, but composers and music editors are also use pedal marks to notate it. The most common symbol for this is a horizontal line below the grand staff, which lift up and down with the pedal. An alternative or older notation is the used to indicating the sustain pedal should be depressed, and asterisk showing should be lifted. Occasionally is general direction at the start of a movement instructing that sustain pedal to be applied continuously throughout. This may be marked with senza sordini in without dampers are the similar wording. In General MIDI, the sustain pedal information is controlled by Control Change number.

5. Sostenuto Pedal

The sostenuto pedal is a similar device that sustain only notes which are depressed at the time of pedal is depressed. It is the usual middle of three pedals but in some upright pianos the middle pedal instead lowers a veil of felt between the hammers and the strings for quiet practising.

6. Half Pedaling

For mechanical pianos it is possible to press down the sustain pedal only partially such that the dampers just touch the strings are very slightly. This technique are advanced pianist is called half pedaling and allows a fine variation of the sound. It can be observed that with half pedaling the damping is more effective for the higher tones. A musical piece that is played with half pedaling by some pianists is Beethoven's Moonlight Sonata. Most recent digital pianos also support this effect.

7. Other Instruments

The electronic keyboards are include a sustain pedal, a simple foot-operated switch which controls the electronic or digital synthesis to produce a sustain effect. Several recent models are used in more sophisticated pedals that have a variable resistance, allowing half pedaling. Vibraphones have sustain pedals are allow from metal bars to ring. Some tubular bells have a sustain pedal. The Cimbalom has a sustain are damper pedal which allows its strings to ring or abruptly mutes them.

Table 1. DCV Specification

Model	3Fm210-M5	3F210-06 3FM210-06	3F210-08 3FM210-08
Type		3port2position	
Fluid		Air(to be filtered by 40µ filter element)	
Operating		Direct acting	
Port size	M5	1/8	¼
Pressure range		0-8.bar (o-0.08Mpa)(0-114Psi)	
Temperature range		-5-60c	
Lubrication		Not required	

I. Literature Review

Intelligent switching control of pneumatic actuator using on/off solenoid valves (KyoungkwanAhn a 2005) [1]

The position control was successfully implemented using on/off solenoid valves instead in expensive servo valves. The valves were pulsed using a modified PWM algorithm which compensated for the dead-time of on/off valves. This was verified by experiments of position control in which steady state errors were reduced to within0.2 mm. The second contribution of this paper was to apply the learning vector quantization neural network (LVQNN) as a supervisor of switching controllers in pneumatic servo systems with on/off valve, where the LVQNN function to classifyed condition of the external load and selects suitable gains of controller for each weight condition. From the experiments of position control of pneumatic cylinder are verified that the proposed MPWM and smooth switching algorithm were very effective to overcome deterioration control performance of transient respons due to four different load conditions and abrupt changes external loads.

Experimenting and modelling the dynamics of pneumatic actuators are controlled by the pulse width modulation (PWM) technique Arcangelo (Messina a2005) [2]

An experimental investigation has been carried out in detail with regard in pneumatic actuators controlled by on-off solenoid valves whose opening and closing time response is based on a pulse width modulation (PWM) technique. The experimental set-up has provid evidence an excellent repeatability along with a noise superimposed on the displacement versus time having a band less than 0.10 mm.

A mathematical model has to been proposed for designing procedures and control strategies within the frame pneumatic position. The mathematical model has been tested and validated through several analytical or experimental comparisons are excellent behaviour has been obtained. The validation have consist in evaluation of four flow-rate characteristics per valve for normal and abnormal flow conditions and evaluation of the kinematic law of opening and closing on-off valve through a laser sensor estimation of the delays between the logic electronic command and the mechanical law of opening and closing on-off valves correlation between real displacement and acceleration of rod and displacement acceleration is obtained from the analytical models respect to ten experimental tests used in only one tuning parameter viscous coefficient tuned on one measured displacement versus time on a trial and error basis.

The analytical/experimental comparisons have shown the ability of theoretical model to provide an accurate mean expectation of the position of the actuator in less than about 2 mm for five cycles over all in ten experimental tests. Due the fact of a feedback normally works with a sampling frequency corresponding to only one cycle, the mentioned performance of the model can be considered attractive especially aimed at applying the same model designing and tuning control strategies based on ratings required from the particular application. Numerical deviation have been provided in order to test possible future models with the model presented here.

Experimental tests on positions control on a pneumatic actuator using on/off solenoid valves (A.Gentile', N 2002) [3]

An application developed in the Mechatronics Laboratory is presented. It is a fast, accurate and inexpensive position-controlled pneumatic actuator that may he applied to a variety of practical positioning applications. The position control was implemented using solenoid valves driven by a novel PWM algorithm and a experimental tuning method for the controller was successfully adopted. The performances of the system were investigated through experimental tests under a variety of conditions. These varied conditions were system mass, input type step, multi steps or ramp and flow control settings on and wide open. The performances obtained are satisfactory compared with the results found in literature and they constitute a label for the system to he surpassed in the future. The actuator's performance is comparable to that achieved by other researchers using servo valves. Current work in this area is focused on the improvement of the system performances using higher control strategy: traditional PID with gain scheduling, adaptive or fuzzy control.

Accurate Sliding Mode Control in Pneumatic Systems Using Low-Cost Solenoid Valves (T. Nguyen, J.2007) [4]

By developing a simple sliding-mode control law, we have used inexpensive components to create an pneumatic actuation system that performs very well. We have demonstrated that the approach only needs simple on/off valves and a position sensors to be implemented. Robustness is achiev with our approach due to its high tolerance for uncertainties in the system dynamics. In addition, the control law only switches the on/off valves when necessary and, therefore, prolongs the valve life and increases the overall reliability of the hardware.

A practical control strategy for servo-pneumatic actuator systems (JihongWang 1999) [5]

The theoretical analysis reveals that the acceleration feedback indirectly represents the cylinder chamber pressure in difference feedback so it is possible to employ acceleration instead of pressure feedback in the construction of servo-pneumatic actuator control systems. Both simulation and experimental results are show that the role of acceleration feedback is similar of pressure difference feedback with respect to the stabilization of pneumatic actuator systems. A moulded PID control strategy is described in this paper to improve in stability of pneumatic actuator systems and to compensate for system nonlinearities. A simple structure is important feature of the control strategy so it is practically feasible for industrial applications.

J. Design Specifications

Table 2. Cylinder

Type	**Double acting Hydraulic cylinder**
Bore Diameter	80mm
Stroke Length	250mm
Cylinder Length	350mm
Force Reaches	2100KN
Piston Rod Diameter	15mm
Supply	Pneumatic

Table 3. Pressure Transmitter

Type	**Silicon –on-sapphire sensor technology**
Pressure range	0-400bar to 0-4000bar
Accuracy	0.25%NLHR
Electrical output	4-20 Ma
Temperature	High operating temperature

Table 4. Pressure Relief Valve

Fluid	NO.6 Fuel
oil Required capacity	1,200 gal/min
Set pressure	150 psig
Over Pressure	10%
Back Pressure	Atmosphere
Inlet relieving Temperature	60F
Dynamic Viscosity	850 Cp
Specific Gravity	0.993

Table 5. Linear Motion Precision Potentiometer

Resistance	1.0K ohms/inch
Linearity	+-0.25%
Electrical stroke	1to36 inches
Mechanical travel	Electrical +1/2 inch
Power Dissipation	1watt/inch @25c
Temperature range	-25c to 100c
Stroke Velocity	Pneumatic = 20 inches/sec

Table 6. Motor

Electric Motor	3hp,1440rpm,50HZ
Tank Capacity	80litres
Vane Pump	Shaft Speed (750-1882)rpm Max.175kgf/cm
Oil grade	servo 68

III. RESULTS AND DISCUSSION

Solid Works Model

A. Double Acting Cylinder

A double-acting cylinder is a cylinder in which the working air acts alternately on both sides of the piston. In order to connect the piston in a double-acting cylinder to an external mechanism, such as a crank shaft, the hole must be provided in one end of the cylinder for a piston rod and this is fitted Double-acting with a gland or 'stuffing box' to prevent escape the working fluids. Double-acting cylinders are common in steam engines but unusual in the engine types. Many hydraulic and pneumatic cylinders use them where it is needed to produce a force in both directions. A double-acting Pneumatic cylinder has a port at each end, supplied with Pneumatic air for both the retraction and extension of the piston. A double-acting cylinder is used to an external force is not available in retract the piston or where high force is required in both directions of travel figure 7.

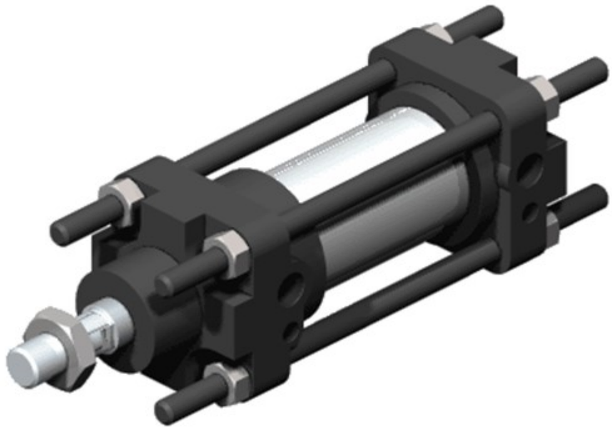

Figure 7. Double Acting Cylinder

B. FRL Units

An airline filter clean the compressed air. It strains the air and traps in solid particles dust, dirt, rust and separates liquids water, oil entrained in the compressed air. Filters are installed in the air line Up stream of regulators, lubricators, directional control valves, and air driven devices such as cylinders and air motors. Pressure regulators reduce and control fluid pressure in the compressed air systems. The regulators are also frequently referred to PRVs pressure reducing valves. Optimally, a pressure regulator maintains a constant output pressure regardless of variations in a input pressure and downstream flow requirements. The practice, output pressure is influenced to some degree by variations in primary pressure and flow. A lubricator adds controlled in quantities of oil into a compressed air system to reduce the friction of moving components.

Figure 8. FRL Units

C. 5/3 DCV Valves

Directional control valves are vital in any pneumatic circuit with directing or blocking airflow to control the speed or sequence of operations. One method of classifying directional-control valves is the flow paths under various operating conditions. Important factors in the number of possible valve positions and the number of ports and flow paths.

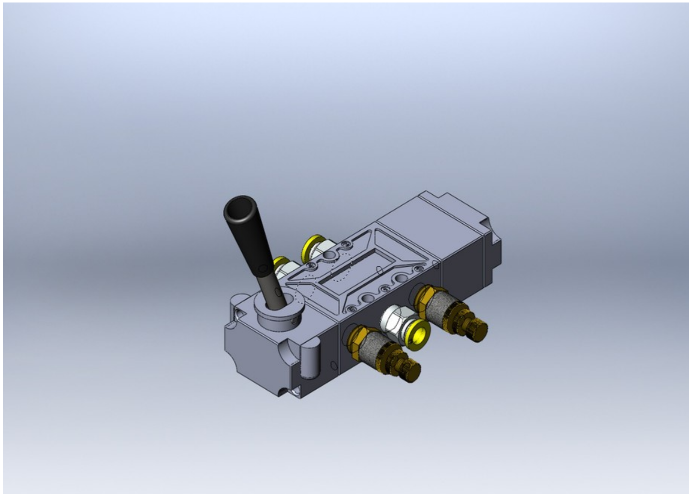

Figure 9. 5/3 DCV Valves

D. ON/OFF Solenoid Valves

The two way, two position valves consist of two ports connected in a passage that can be opened or blocked to control flow through the valve. Usually, an electrically activated solenoid shifts of valve spool or poppet to direct flow. The valve provid an easy on-off function, which many systems use to interlock, isolate, and connect various system parts.

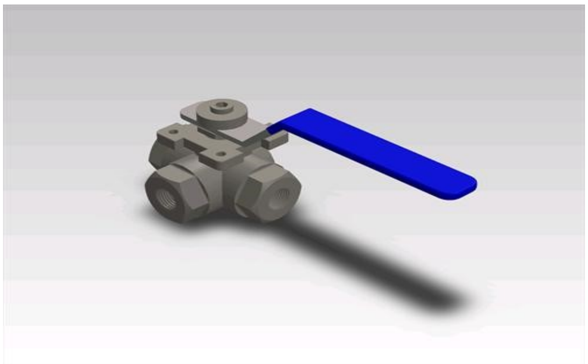

Figure 10. ON/OFF Solenoid Valves

E. Foot Pedal Valve

If Offered in 3- or 4-way models, these Foot Pedal Valves are used in unlimited applications in factory automation. Two versions are offered either a low-profile flat pedal or a standard pedal with are without a guard. These valves offer in operating pressure range of 0 to 150 psig, operating temperature range of 32 to 140°F and 1/4” NPT ports.

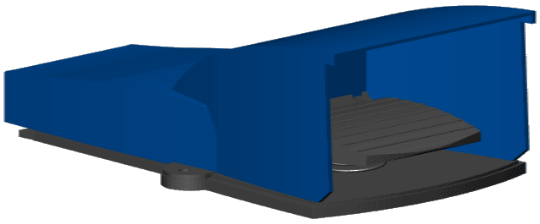

Figure 11. Foot Pedal Valve

F. Controlling The Accurate Position Of Pneumatic Actuator Using Solenoid Valves

The source of voltage comes to control station through serial interface 115Kps.Then the control station gives output in 300Hz to amplifer data aquitision and PWM drives.The aquitision give the input signal for air valve and PID valves gives signal to position sensor to torque sensor and send to the pressure to actuated the pneumatic actuator.

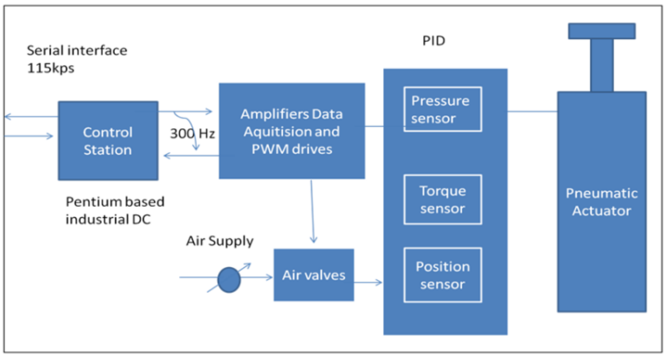

Figure 12. Controlling The Accurate Position of Pneumatic Actuator Using Solenoid Valve

G. ON/OFF Controller For Pneumatic Actuator

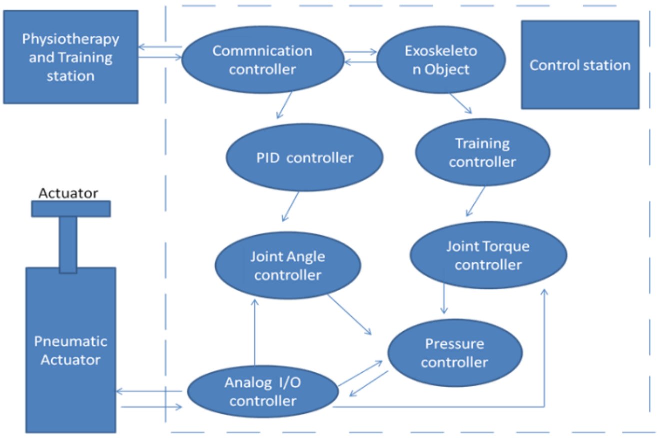

Figure 13. ON/OFF Controller For Pneumatic Actuator

H. Pulse Width Modulation Controller

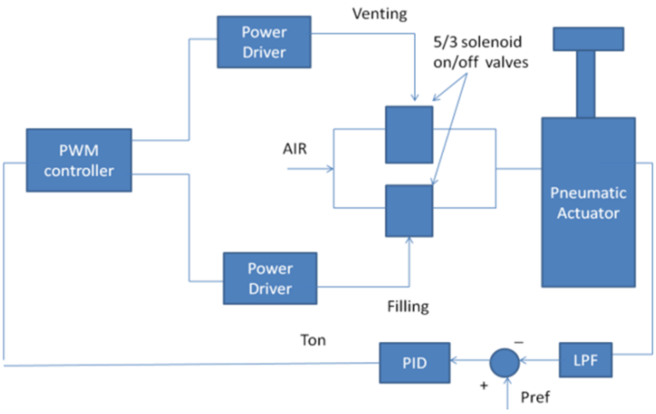

Figure 14. Pulse Width Modulation Controller

I. Implementing The PID Controller In Pneumatic Actuator

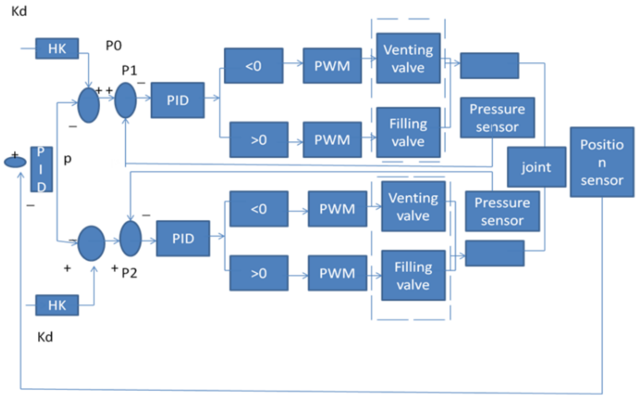

Figure 15. Implementing The PID Controller In Pneumatic Actuator

IV. CONCLUSION

A fast accurate and inexpensive position in controlled pneumatic actuator that may be applied to a variety of practical positioning applications was developed. The position control was successfully implemented using on/off solenoid valves. The valves were pulsed using a novel PWM algorithm which produced a very linear open-loop velocity response. The open-loop characteristic was shown both theoretically and experimentally to be near symmetrical, despite the difference in the cross-sectional areas of the piston due to the rod. A comparison of open and closed loop responses of the standard PWM techniques and that the novel PWM technique shows that there has been a significant improvement in the control. A linear model was identified for the open-loop plant from experimental data. The model parameters obtained at mid stroke were used in combination with manual tuning to tune a PID controller. Coulomb friction compensation combined with bounded integral control was found to substantially reduce the steady-state error due to striation. The actuator's accuracy was limited by the accuracy of the potentiometer and the A/D resolution. A worst case steady-state accuracy of 0.21mm was achieved. The actuator can respond to commanded moves as small as 0.11 mm. Position feed forward was used to reduce the following error to S-curve profiles. Following errors less than 2.0 mm were achieved. The actuator's performance was robust to changes in the system mass. A sixfold increase in the mass increased the Trouble shoot in closed loop control by 1 mm, but did not affect the rise time or the steady-state accuracy. The actuator's overall performance is comparable to that achieved by other researchers using servo valves.

V. REFERENCES

[1]. Accurate Position Control a Pneumatic Actuator Using On/Off Solenoid Valves Robert B. van Varseveld and Gary M. Bone 3, SEPTEMBER 1997

[2]. Experimental tests on position control of a pneumatic actuator using on/off solenoid valves A. Gentile', N. 1. Giannncearo', G. Reina" 'Department die Ingneria dell'lnnovazione University die Lecce Via per Monteroni 73 100 Lecce (Italy)

[3]. Intelligent switching control oF pneumatic actuator using on/off solenoid valves Kyoungkwan Ahn a,*, Shinichi Yokota ba School of Mechanical and Automotive Engineering, University of Ulsan, San 29, Muger 2dong,

[4]. Van Varseveld, Robert B., and Gary M. Bone. "Accurate position control of a pneumatic actuator using on/off solenoid valves." IEEE/ASME Transactions on mechatronics 2.3 (1997): 195-204.

[5]. Gentile, A., N. I. Giannoccaro, and G. Reina. "Experimental tests on position control of a pneumatic actuator using on/off solenoid valves." Industrial Technology, 2002. IEEE ICIT'02. 2002 IEEE International Conference on. Vol. 1. IEEE, 2002.

[6]. Ahn, Kyoungkwan, and Shinichi Yokota. "Intelligent switching control of pneumatic actuator using on/off solenoid valves. " Mechatronics" 15.6 (2005): 683-702.

[7]. Chillari, S.; Guccione, S.; and Muscato, G. (2001). "An experimental comparison between several pneumatic control methods." Proc.of 40th IEEE Conf. on Decision and Control, Orlando, FL, Dec.2001, pp1168-1173

[8]. Menz W, Dimov SS. Editorial for the special issue of IJAMT on multi material micro system manufacturing. IJAMT 2007; Vol 47, Issues (1-4):73-74.

[9]. Muto T, Kato H, Sakamoto K. Digital control of hydrostatic transmission system driven bydifferential pulse-width modulation. Trans JSME Part C 1995;61:3983–90.

[10]. Noritsugu T. Development of PWM mode electro-pneumatic servomechanism, Part I: Speed control of a pneumatic system. J Fluid Control 1987;17(2):65–79.

[11]. J. Tang and G. Walker, "Variable structure control of pneumatic actuators," ASME J. Dynamic Syst., Measur., Contr., vol. 117, pp. 88–92, Mar. 1995.

[12]. B. W. Surgenor and H. N. Iordanou, "Experience with advanced position control of a pneumatic systems," presented at the IFAC Workshop: Trends in Hydraulics and Pneumatics, Chicago, IL, Nov. 1994.

[13]. J. Pu, R. H. Weston, and P. R. Moore, "Digital motion control and profile planning for pneumatic servos," ASME J. Dynamic Syst., Measur., Contr., vol. 114, pp. 634–640, Dec. 1992.

[14]. Van Verseveld R.B., Bone' G.M., 'Accurate position control of a pneumatic actuator using on/off solenoid valves' ' Transactions on Mechatronics, Vol. 2 n. 3 Sep. 1997.

[15]. Figliolini G., Sorli M., 'A pressure control system with digital electrovalves modulated in pwm and controlled via PIC', 6Ih Int. Workshop on Robotics in Alp.