DESIGN, FABRICATION AND CONTROL OF HYBRID PNEUMATIC ACTUATOR

[1]N.Balaji, [2]V.K.Hari prasath , [3]dhanasekar J

[1]Student, [2]Student, [3]Assistant Professor
[1]Department of Mechatronics ,
[1]Bharath Institute of Higher Education And Research , Chennai, Tamil-nadu .

Abstract: This paper is concerned with the problems of position-controlled pneumatic servo drive. The position control is designed using low-cost two position solenoid valves in place of costly proportional valve. Continuous positioning can be made with servo/proportional valve, but the cost of the servo/proportional valve is relatively very high. This project aims at developing a low cost, efficient and accurate position control system for pneumatic actuators eliminating servo /proportional valves, thereby reducing the cost. Here a simple on/off valve with electronic Arduino controller is used to overcome the cost effective problem. The control methods based on simply on/off control algorithm and on pulse-width-modulation (PWM) algorithm using Arduino UNO microcontroller. To develop a servo pneumatic hybrid actuator for position control with fast response, large stroke and high accuracy (through lead screw arrangement).

Index Terms **- Pneumatic, Multi position control, Hybrid control, On/Off solenoid and PWM control.**

1.1INTRODUCTION

Pneumatic Systems which uses compressed air plays an important role in the part of modern day industrial world. Pneumatic systems have many advantages over conventional electro-hydraulic or electro-mechanical systems. It is relatively cheap and easy to build a pneumatic system .The concept behind Pneumatic systems are the conversion of compressed air (mechanical energy) into a useful work non industrial applications includes house hold appliances like blowers, vacuum cleaners etc that uses compressed air in one way or another. Jackhammers and power drills are some of the industrial based applications that use compressed air to perform the specified work. Robotic world utilizes pneumatic actuation in recent times. Robot manipulators are designed and developed to perform certain hectic operations of humans. The robotic manipulators include robotic arms, which are widely used in pick-and-place operations. The main advantages of pneumatic systems are due to their high payload-to-weight ratio, high payload-to- volume ratio, and high speed and force capabilities compared to electric actuators. Pneumatic systems are designed with fire and explosion proof based systems. Another main factor favoring the use of pneumatic systems is the ready availability of air supply. Besides, leakage in conventional electro hydraulic system is always a potential problem. Lastly, pneumatic systems are insensitive to temperature changes unlike hydraulic systems, in which, fluid viscosity depends greatly on temperature. Even though pneumatic systems inherently possessed a lot of qualities, they also have many disadvantages mainly because it is difficult to control such systems.

Pneumatic actuators are characterized by higher order dynamics rather than the second order dynamics followed by the hydraulic and electrically based actuators. If the PID controller gains are high indicates the instability of the third and fourth order dynamics systems. In addition, the characteristic of compressible air flow contributes a highly nonlinear component to the overall system dynamics. Nonlinearity is always hard to deal with from a system standpoint. The compressibility of air also causes the system to have poor damping and low stiffness. Unlike the hydraulic fluid which requires lubrication to avoid friction, a pneumatic system lacks it. The low bandwidth of the system hinders the process of system identification through classical frequency response method. When compared with the electro hydraulic systems the accuracy and repeatability of the pneumatic system is low. In this thesis, the challenge is to provide some possible control strategy that will attempt to overcome the above-mentioned known problems. Although pneumatic systems are hard to control, the continued progress of control technology in nonlinear systems has slowly helped to outweigh its many disadvantages. Over the years, pneumatic actuators are extensively used in industrial automation for applications that require only two end positions of a stroke, with no stops in between, i.e. for pick-and-place positioning problems. In order to obtain more positions, designers had to add switching devices to their equipment so a received signal informs if machine control element is properly positioned. Changing the positioning task is required to deploy the switching device. Therefore, for the flexible positioning operations in positions between two end positions some other motion technologies based on costly electromechanical systems are used works of position- control systems for pneumatic drives have been realized. In most of them relatively expensive proportional servo valve are used.

1.2 OBJECTIVE OF THE WORK

In this paper, in place of costly proportional valve a low-cost on/off solenoid valve control is achieved. The objective is to develop the cheaper pneumatic servo drive with characteristics close to system with proportional valve. Because of the delay of valve feedback and their discrete on/off feature precise control is difficult to achieve. This problem can be resolving by using an Arduino Uno based PWM signal, which controls the cylinder positioning by actuating appropriate solenoid valves in the pneumatic system. Through pneumatics the fast response can be achieved and required stroke length but to improve accuracy have to implement a lead screw arrangement driven by a stepper/Pneumatic motor.

2 METHODOLOGY

The position control is implemented using low-cost two position solenoid valves in place of costly proportional valve. The control method based on pulse-width-modulation (PWM) algorithm using Arduino UNO microcontroller. There is lot of control methods were used for pneumatic position control. Some of the methods are

- On/off solenoid valve control
- Proportional/servo valves
- Pneumatic fuzzy controller method
- Using fuzzy PID
- PID controller
- Proportional pressure regulator method
- PLC (programmable logic controller)

The Problem of the existing method were

- The on/off valve has very low response.
- Positioning is already predetermined one.
- Accuracy of the existing system is very poor.
- Continuous positioning can be made with servo/proportional valve, but the cost of the servo/proportional valve is relatively very high.

Over the years, pneumatic actuators are enormously used in industrial automation for applications, which require only two end positions of a stroke, with no stops in between, i.e. for pick-and-place positioning problems. In order to obtain more positions, designers had to add switching devices to their equipment so a received signal informs if machine control element is properly positioned. Changing the positioning task is required to deploy the switching device. Therefore, for the flexible positioning operations in positions between two end positions some other motion technologies based on costly electromechanical systems are used works of position-control systems for pneumatic drives have been realized. In most of them relatively expensive proportional servo valve are used .Positioning is predetermined one.

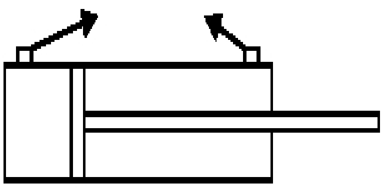
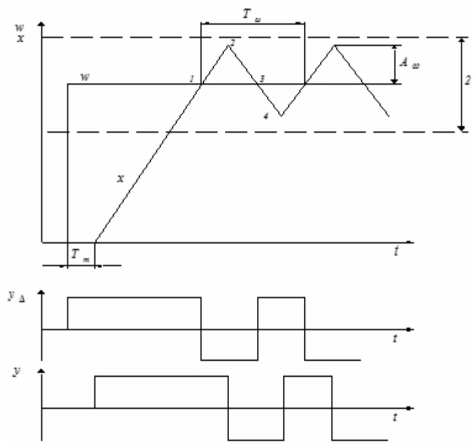


Figure 1.Positioning Predetermined Diagram



Tm	-	Dead time
x(t)	-	Output value
W(t)	-	Desired value
Tw	-	Period
Aw	-	Amplitude
yΔ	-	Output of a ideal relay
Y	-	Output of a real relay

Figure 2.Response of Pneumatic Drive Using On/Off Valve Control

CONCEPTUAL DESIGN OF THE CONTROLLER

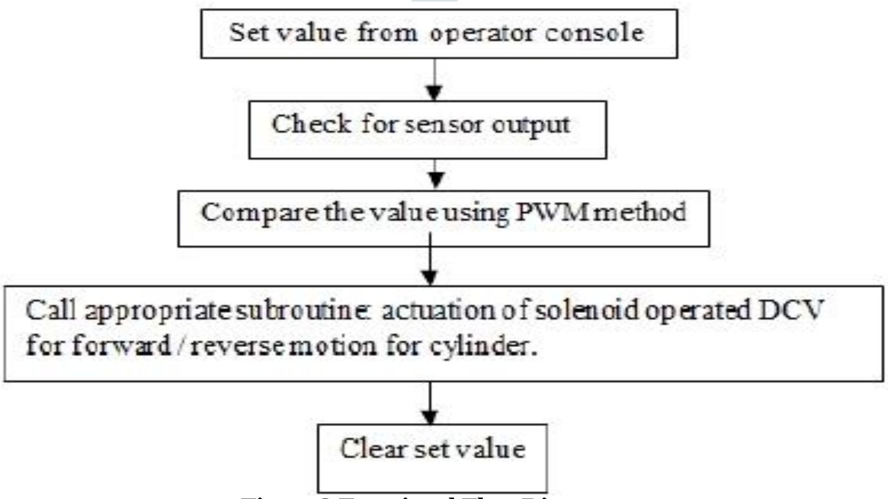


Figure 3.Functional Flow Diagram

The conceptual design starts with the product specification, and leads to the overall concept of the design solution. It is first necessary to explore further the functions of the proposed product. This can be done with a simple function flow diagram. The Functional Flow diagram is given above in Figure 3.

3.1 EMBODIMENT DESIGN OF THE CONTROLLER

In embodiment design phase, let make those design decisions, which will determine the physical, and software manifestation of the system. The overall goal will be to produce hardware and software structural designs.

Hardware Strand:
Solution technology **-** Microcontroller-based Peripheral
Functions **-** PWM Modules, ADC modules, Timers, Parallel port Hardware Layout.

Software Strand:
Language **-** Assembler for on-board controller
Program Structure **-** Main program initializes and stays in loop.

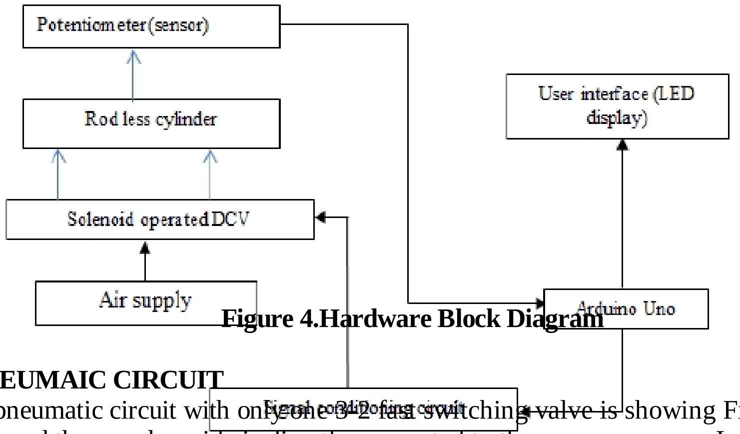


Figure 4.Hardware Block Diagram

3.2 DESIGN OF THE PNEUMAIC CIRCUIT

A new design of pneumatic circuit with only one 3-2 fast switching valve is showing Fig.5 .The valve is connected to the full diameters of the piston and the annul us side is directly connected to the pressure source .In this circuit, the cylinder retracts,

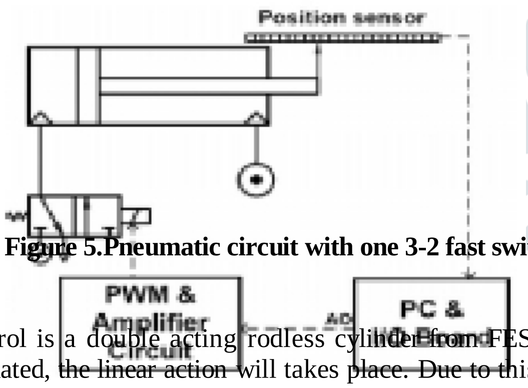


Figure 5.Pneumatic circuit with one 3-2 fast switching valve

4.1 EXPERIMENTAL SETUP

The actuator under control is a double acting rodless cylinder from FESTO with 100mm stroke is used to position the piston. Whenever the cylinder actuated, the linear action will takes place. Due to this the potentiometer resistance will also varied, this analog feedback will be given to the microcontroller for controlling the solenoid valves in the system. Actually the feedback is an analog signal that will in range of 0 to 5V. That analog signal is converted to digital signal using microcontroller. The microcontroller had a built-in ADC module, PWM module that produces a signal to control the solenoid. In between this a solenoid driver circuit is used. Because the output from the microcontroller signal in the range of 0 to 5volt, whereas the solenoids are operated in range of 24V, so an isolation circuit designed and bridged with it. The microcontrollers have 20 MHz crystal, so the operating speed is comparatively very high. Due this the response of the system is high. The solenoid driver circuit consists of TIP122 and a Darlington pair. From this circuit, the solenoid operated directional control valve is actuated. By means of this controlling action the positioning of pneumatic cylinder has been done.

The media supervised by the solenoid valve enters the valve through the inlet port (Part 2 in the illustration above). The media must discharge through the orifice (9) before continuing into the outlet port (3). The orifice is closed and opened by the plunger (7).The valve pictured below is a normally- closed solenoid valves. Normally-closed valves use a spring (8) which presses the plunger tip opposed to the opening of the orifice. The sealing material at the tip of the plunger keeps the media from enter into the orifice, until the plunger is held up by an electromagnetic field created by the coil.

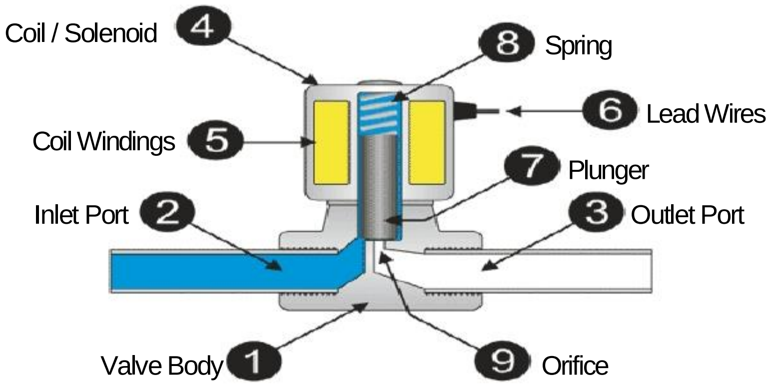


Figure 6.PneumaticSolenoid

Pulse width modulation (PWM) is a powerful method for controlling analog circuits with a processor's digital outputs. The DC voltage is converted to a square-wave signal, alternating between fully on (nearly 24v) and zero, giving the solenoid a series of power "kicks". If the switching frequency is high enough, the electrical actuator actuated at a steady speed. By modifying the duty cycle of the signal (modulating the width of the pulse, hence the 'PWM') i.e., the time fraction it is "on", the average power can be varied, and hence the motor speed. The PWM switching frequency diagram is shown in Figure 7.

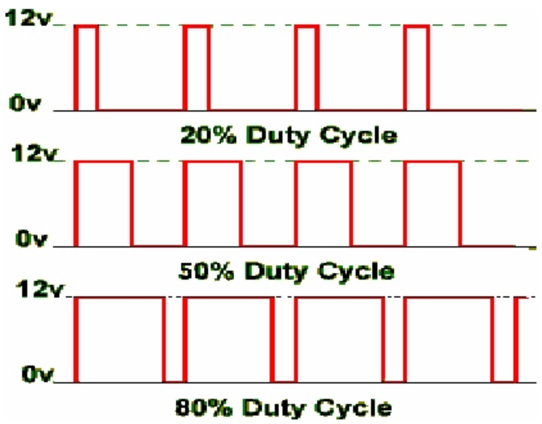


Figure7.PWM Switching Frequency diagram

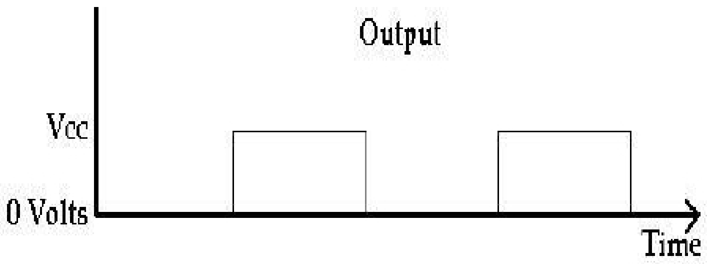


Figure8. Pulse Width Modulation With 50% Period

To control the actuation of the solenoids or speed of the motor the amount of current going through the device is controlled. The current only flows when the output is low (for microcontroller's solenoid or LED or electrical actuator circuits are usually wired so current flows into the microcontroller when the output is low). The output of microcontroller will look like the following square wave. The diagram of Pulse Width modulation with 50% period is shown in Figure 8. By turning a solenoid or motor on and off fast enough then it will appear to stay on continuously and since there is less current flowing overall solenoids will appear less actuation and the motor will run at a slower speed. With this solution can make and solenoids actuated and off as slow as 30 times a second but any slower and start to see the LED or other electrical parts are blinking which is not the desired result. Or, for the motor, it will lose its smooth operation and get shaky. The solution does not work very well because and solenoid or electrical parts are still rather actuated 30 times a second.

Rather than changing the number of times the output goes on and off change how long the output stays on and off. Let's take a deeper look at one output cycle. An output cycle consists of a low period t_{tlow} and a high period, $t_{high\cdot\, tlow} + t_{high} = T$, where T is the period (length of time) for single output cycle. t_{high} is also known as an output pulse, or just pulse.

The detailed diagram for PWM switching frequency is shown in Figure 9. Always keep T the same so that there are always the same numbers of output cycles per second. If width of t_{high} is increased then decrease t_{low} to keep T the same. If t_{high} is decreased then must increase t_{low}. For the case thigh is made small then the output looks like the following.

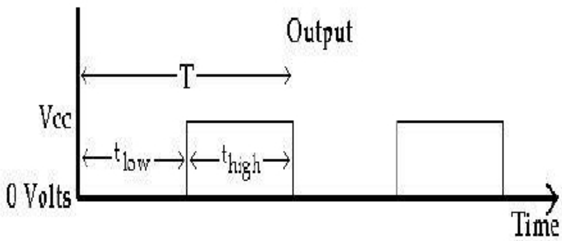


Figure9. Detailed Diagram for PWM Switching Frequency

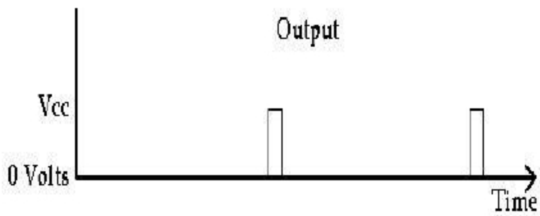


Figure10.Pulse Width Modulation With 10% 'On' Period

The diagram of Pulse Width Modulation With 10% "On" Period is shown in Figure 10. Output is 0 most of the time and the solenoid or motor will be on most of the time. For the case that lets make t_{high} large then the output looks like the following. The diagram of Pulse Width Modulation With 90% „On" Period is shown in Figure 11.

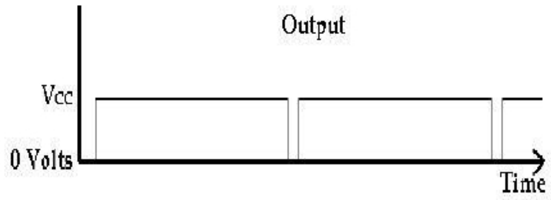


Figure11. Pulse Width Modulation With 90% 'On' Period

The output is Vcc most of the time, which turns off the solenoid. The current only flows through solenoid for the brief time that a solenoid is on during $\mathbf{t}_{low}$. But since the solenoids are turned on and off very fast, solenoids actuation cannot be seen, and it appears very low in audible. The total current that flows through solenoid is low. For the motor it will efficiently turn at a low speed. So by controlling the actuation solenoid or the speed of a motor by changing the width of t_{high} . This is the secret of Pulse width Modulation. The below is the formula for setting the PWM period in PIC microcontroller that could be programmed by software.

PWM Period = [(PR2) + 1] •4•TOSC•PWM frequency is defined as 1/ [PWM period]

The controlling signal having variation in pulse width is called as pulse with modulation. This can be generated by PIC microcontroller. The PWM output diagram is shown in Figure 12.

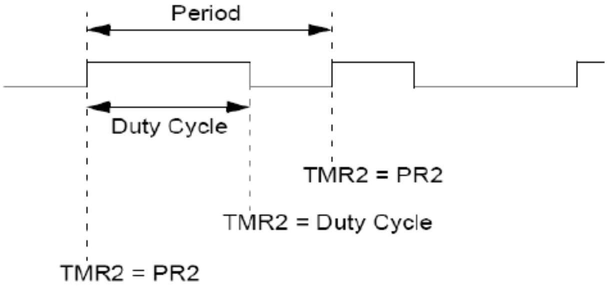


Figure12. PWM Output

The Arduino Uno based on the ATmega328. It has 14 digital pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

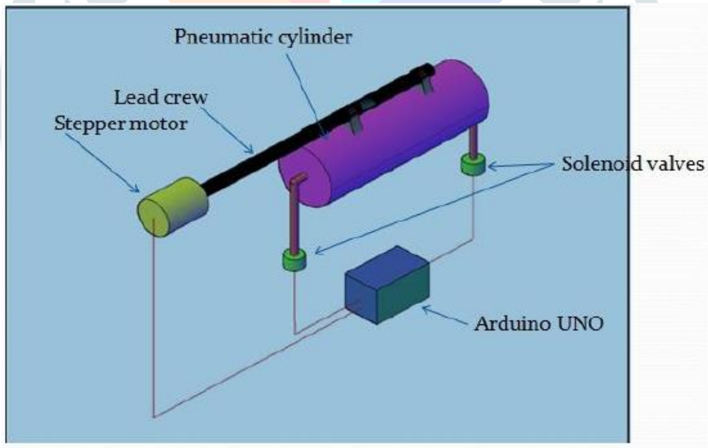


Figure13. CAD Model of the Hybrid Pneumatic Actuator

4.2 SYSTEM SOFTWARE DESIGNALGORITHM FOR THE SYSTEM

Main program

Step1: Start the operation.
Step2: Get the analog value from the potentiometer.
Step3: Change the analog value into digital value.
Step4: Display the digital value in the LED display
Step5: Compare the digital value to the actual set value.
Step6: Get PWM signal in port 8 and 9.
Step7: Send the signal to the signal conditioner circuit (TIP122).
Step8: Actuate the solenoid operated DCV according to the signal.
Step9: Check whether the cylinder moved required distance.
Step10: If yes go to next step otherwise go to step 2.
Step11: Get the new set value and go to step 1.
Step12: Stop the operation.

End of the program

Position of the piston is identified by position of variable end of the rheostat which is attached with the piston. For each and every position of the rheostat corresponding voltage value is calibrated against the position of the piston .Thus from the voltage value of the rheostat we can find the current position of the piston. As per the requirement the value are entered into the keyboard connected to the Arduino. Arduino will keep track of the required position and the current position .Once the controller obtained the required position from the user it will calculate the two positions on both side of the required position which is exactly 10 mm from require position. Reason for calculating this position is that system will be controlling the piston by on/off till it will reach this position .According to the current position and required position the processor will select the corresponding solenoid. Then the control will shift to PWM control .By changing this control from On/Off control to PWM control we can avoid oscillation that will occur due to fast reactions of the piston .During the PWM control the movement of the piston is controlled precisely. By this method of On/Off control and PWM control we can obtain a maximum accuracy of 1mm.

4.3 HYBRID CONTROL OF THE PNEUMATIC ACTUATOR

For further improving the accuracy and precision the entire pneumatic cylinder is mounted on a lead screw arrangement which runs on stepper motor .Once the PWM control method finished its cycle the Arduino will check for the accuracy below one mm .According to the requirement the stepper motor will run in clockwise or anticlockwise direction thus moving the entire cylinder such that the piston reaches its required position with the accuracy of 0.1mm.

CONCLUSION

In this project an inexpensive pneumatic servo drive for translational positioning task, which uses low cost on/off solenoid valves, had been implemented. The control methods based on simply on/off control algorithm and control methods based on pulse width modulation (PWM) algorithm were implemented using the Atmega controller in the Arduino UNO. This project is more suitable for simple as well as complex pneumatic automation system, which can control up to eight actuators. It gives the full flexibility to high degree of sophisticated automation. PC &PLC control is replaced by much reliable high speed microcontroller even suitable for rocket launching and space applications. Microcontroller can work underwater, on ground, air and even on out space, it consuming much low power than any other alternative. A complete literature survey has been carried out for design of the pneumatic actuator. Through pneumatics we can achieve the fast response and required stroke length but to improve accuracy have to implement a lead screw arrangement driven by a stepper/Pneumatic motor.

REFERENCES

[1] AsgharRaoufi, Brian Surgenor (2003) "Design and evaluation of a pneumatic gantry robot for the grinding of steel blanks"-Proceeding of the Conference, IMECE2003-41701.November 16-21.

[2] Barr, Michael (2003) "Pulse Width Modulation" Embedded Systems Programming, September, pp. 103- 104.

[3] GrzegorzGranosik, Borenstein (2004) "Minimizing Air Consumption of Pneumatic Actuators in Mobile Robots"-IEEE International Conference on Robotics and Automation, New Orleans, LA., April 26-May 1, pp. 3634-3639.Mark R. Jolly (1999) "Pneumatic motion control using magneto rheological fluid technology"- Proceeding of the Conference, International Center for Actuators and Transducers (ICAT). April 22-23, pp 417.

[4] Ming-Chang Shih and Niarn-LiarngLuor (1999) "Self- Tuning Neural Fuzzy Control the Position of a Pneumatic Cylinder under Vertical Load" - Proceeding of the Conference, Master Thesis of Dept. of Mech.Engrg. at National Cheng Kung University,Taiwan.

[5] ŢeljkoŠitum, BrankoNovaković and JoškoPetrić (2000)"Sliding Mode Control Applied to Pneumatic Servo drive"-Proceeding of the Conference, 6th International Scientific Conference on Production Engineering CIM 2000, Lumbarda - Korčula, p.p. II- 025-II-032, Croatian journal.

[6] TatsuhikoImaizumi , Osamu Oyama , Toshihiro Yoshimitsu (2001) "Study of Pneumatic Servo System Employing Solenoid Valve Instead of Proportional Valve by Keeping the Solenoid Valve Plunger to be Floating" - Proceeding of the Conference,Journal of the Japan Hydraulics & Pneumatics Society, 29-7, pp 344/349.

[7] Ajay V Deshmukh (2005) "Microcontrollers Theory and Applications". Publisher -Tata Mc-Graw-Hill.

[8] Tim wilmshurst (2004)"An Introduction to the design of small scale embedded systems" Publisher-Palgrave.

[9] ŢeljkoŠitum, BrankoNovaković and JoškoPetrić (1999)"Identification and Control of Pneumatic Servo drives" - Proceeding of the Conference, 5th International Scientific Conference on Prod. Eng. CIM'99, Opatija, Croatian journal.