Position Control of a Servopneumatic Actuator using Fuzzy Compensation

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Abstract

Modern servopneumatic positioning technology has made significant inroads in the automated manufacturing environment. The advantages cited by end users include the speed of motion, low cost of installation and maintenance, cleanliness, and the simplicity of operation of these systems relative to other similar hydraulic and electro-mechanical technologies. The robustness of servopneumatic technology solutions is limited by the positioning accuracy of current system controllers. Servopneumatic controllers typically rely on sophisticated control algorithms that accommodate the highly non-linear nature of pneumatic actuator operation. Current positioning accuracy is approximately 1% of the stroke length. System non-linearities include the presence of both static and dynamic actuator friction. Compensating for this stick-slip type of friction which occurs at low velocities is imperative for good positioning accuracy. Taken as a whole, these system characteristics provide an ideal modern laboratory setup for instruction in the use of positioning controllers and the development of supporting control methodologies.

The development of several novel undergraduate laboratory modules devoted to the use and understanding of this modern servopneumatic system and implementation of fuzzy based control methods is presented. These modules include an introduction to servopneumatic systems, position control using a standard industry controller, Numerical Control (NC) programming, calibration of proportional flow control valve, results of an implementation of position control using proportional plus integral and derivative (PID) control and alternative control algorithms. The PID control performs much the same function as a feedback controller, but with a more elaborate algorithm for determining its output. It looks at the current value of the error, the integral of the error over a recent time interval, and the current derivative of the error signal to determine not only how much of a correction to apply, but for how long. This three quantities are each multiplied by a "tuning constant" and added together to produce the current controller output
Important concepts addressed in the laboratory modules include:

1. Understanding response patterns of the system and development of a friction compensation technique using a fuzzy logic based model of the system.
2. Comparison of the response patterns of the above control systems with respect to positioning accuracy and other parameters.

Introduction

The development of several novel undergraduate laboratory modules devoted to the use and understanding of modern servopneumatic actuators is presented in the remaining sections of this paper. Advantages cited by end users of these systems include the speed of motion, low cost of installation and maintenance, cleanliness, and the simplicity of operation of these systems relative to other similar hydraulic and electro-mechanical technologies. These characteristics have a very positive impact on the use of these systems in the educational laboratory environment. The robustness of these

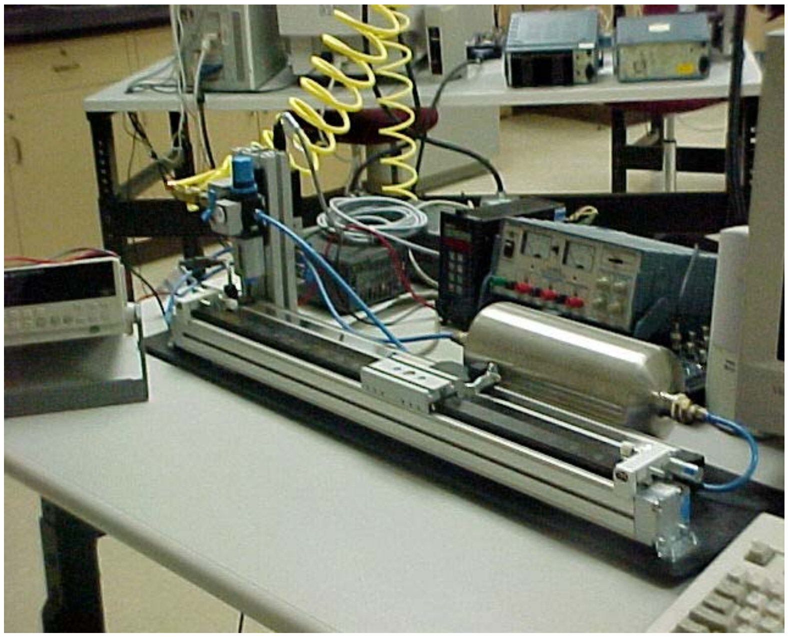


Figure 1. Festo™ Servo Pneumatic Actuator & Control System

servopneumatic actuator systems is typically limited only by the positioning accuracy of system controller.

Three laboratory modules utilizing the industrial Festo™ servopneumatic actuator and control system shown in Figure 1 were developed for an introductory electromechanical systems class for four year electronics and mechanical engineering technology students. The first laboratory module is devoted to an introduction of the pneumatic hardware, NC programming of the controller, and calibration of the actuator carriage motion. A realtime PID algorithm is implemented in SIMULINK™ a program developed by Mathworks™, on a ancillary personal computer and acquisition system in the second laboratory module. The final module utilizes the second module's hardware and software setup to introduce and implement a software-based fuzzy controller. Implementation of laboratories required use of the base Matlab™ and SIMULINK™ software, two add-on modules and one-third party data acquisition module for Simulink™.

Standard Position Control of Servopneumatic System

The Festo™ servopneumatic system consists of the following components:

- an axis controller (Model SPC 100)
- a proportional directional control valve (Model MPYE)
- a compressed air service unit with 5 micro meter filter
- a displacement measuring system – Linear Potentiometer
- a double piston cylinder with mechanical guide
- 24 V Power Supply

The axis controller, valve, cylinder and displacement measuring system are connected to form a closed-loop control circuit. In this control circuit, the position of the slide/carriage represents the controlled variable. Figure 2 shows the principal structure of a positioning

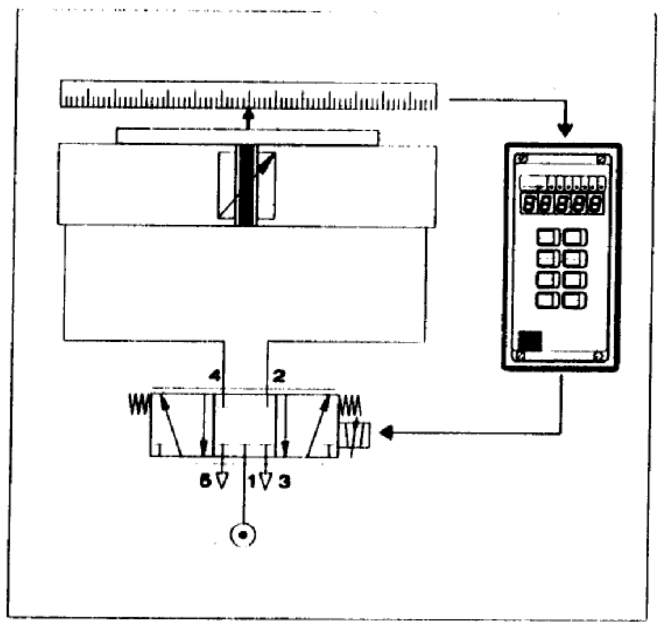


Figure 2. Structure of a positioning control circuit with pneumatic components

control circuit with pneumatic components. The measuring system continually acquires the position of the slide and transfers this as an electrical signal to the axis controller. The latter compares the stored setpoint position with the actual position and generates an analog control signal to the proportional directional control valve. The proportional directional control valve controls the carriage by adjusting the differential pressure across the double sided cylinder piston.

Axis Controller SPC 100

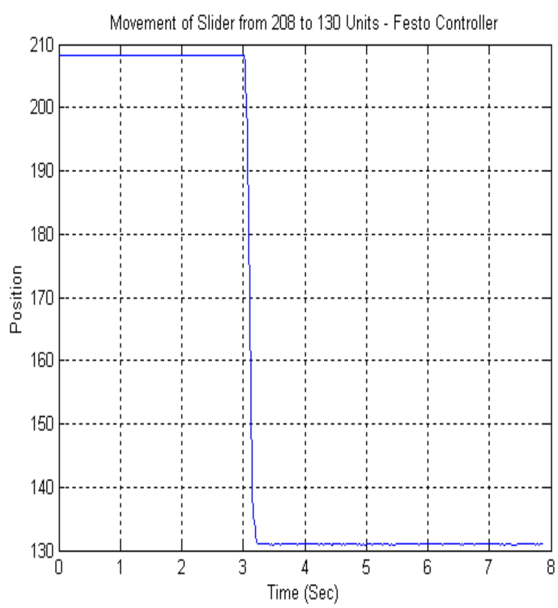
The core of the positioning system is the axis controller SPC 100 that primarily performs the following tasks:

- specifying the setpoint position via the positioning control
- comparing the setpoint and the actual positions and the closed loop control via appropriate actuation of the proportional directional control valve

A linear potentiometer is used as a displacement measuring system to establish the actual slide position. The control panel on the front of the SPC 100 consists of a touch sensitive keyboard, a 5-figure display, and an LED Strip. The LED strip shows the actual active function. In the laboratory students are taught basic NC oriented programming techniques using manual inputs to the controller. All functions of the system including commissioning, programming, operation and diagnostics are executed directly on the SPC 100 in a manner similar to the approach used in an industrial setting.

Response of Festo™ Controller

The response of the Festo™ Controller from the intial position to desired position as shown in Figure 3. Figure a & b shows the movement of slider from 208 to 130 units (right to left) and from 24 to 130 units (left to right).



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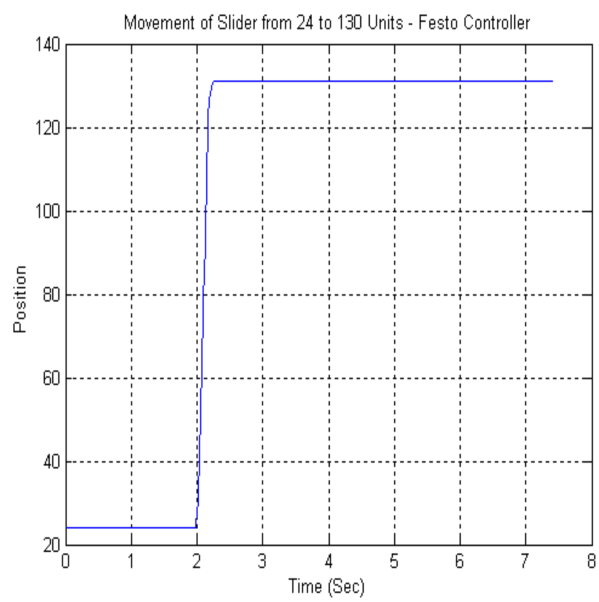

b

Figure 3. Position response of SPC 100 Controller

Position Control of Servo Pneumatic system – using PID Controller

The software based PID controller, valve, cylinder and displacement measuring system are connected to form a closed-loop control circuit. In this control circuit, the position of the slide represents the control variable. The measuring system continually acquires the position of the slide and transfers this as an electrical signal to the PID controller. The latter compares the stored setpoint position with the actual position and calculates the control signal for the proportional directional control valve.

PID Experimental Setup

The experimental set up is composed of a servo-pneumatic system, a PCI 6024E DAQ board (Supplied by National Instruments), and a Pentium based PC. The servopneumatic system (supplied by Festo™ Corp.) consists of a proportional flow control valve (MPYE-5), a source for compressed air, a cylinder for storing compressed air, a double acting rodless cylinder, a slide attached to the piston, and a linear potentiometer attached to the slide.

With the MPYE valve, the valve-slide stroke is controlled proportionally to a specified set point. The analog electrical input signal to the MPYE produces a stepless variation of the flow rate. The MPYE thus controls the flow rate regard its magnitude and direction. The MPYE valve operates between 0 and 10V. At 5V input, the flow rate is disabled. As the voltage input is decreased from 5 to 0V, the flow rate increases in the negative direction. As the input voltage is increased from 5V to 10V, the flow rate increases in the positive direction. Figure 4 below illustrates the output of the MPYE proportional control valve. The potentiometer outputs a voltage proportional to the position of the slide. The potentiometer operates between 0 and 10V.

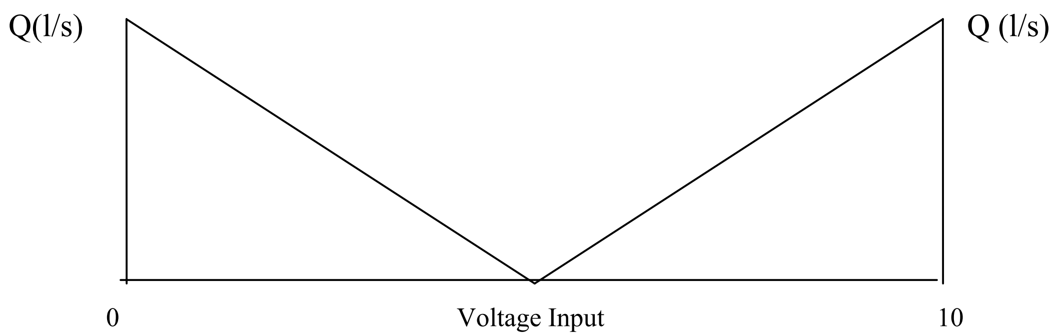

Figure 4. Schematic of the MPYE Proportional Servo Valve

As the flow rate into and from the rodless cylinder is varied through the MPYE valve, the pressure on either side of the piston in the rodless cylinder is varied. Resulting force imbalance causes motion of the piston. The position of the piston is measured via the analog potentiometer.

Electrical connections to and from the PCI 6024 E DAQ card are provided. A 24V power input is supplied to the proportional valve. A 15V-power input is supplied to the potentiometer. The PCI 6024E DAQ board (BNC 2120), supplied by National Instruments, include various input and output channels. For this set up, one analog input channel (to supply control input to the proportional flow valve) and one analog output channel (to obtain the potentiometer output) was used.

The PCI 6024 E DAQ board is connected to a Pentium based computer. Matlab was used to implement the controller program, in real-time. The controller program was developed using Matlab's Simulink™ programming language. The analog input and output channels were configured using the DAQ channel wizard supplied by National Instruments. Figure 5 shows the schematic of the experimental setup.

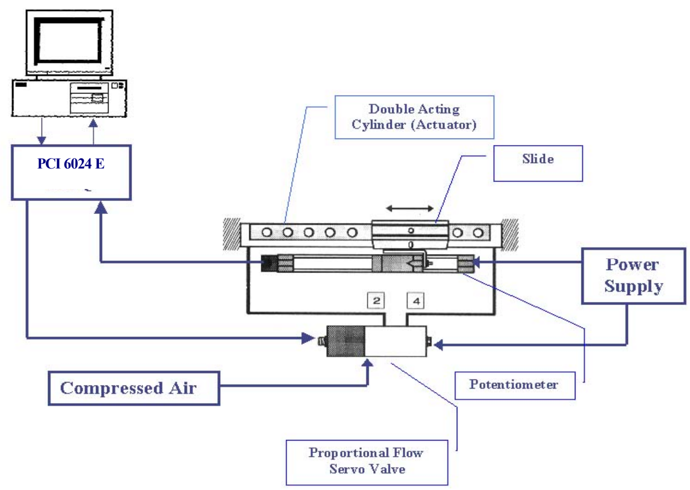

Figure 5. Schematic of the Experimental Setup

The PID Controller was implemented using Simulink™, real time control. The Simulink™ model is given below in Figure 6

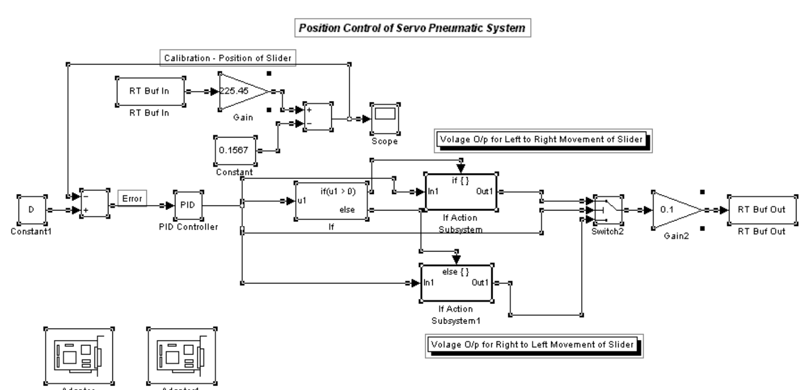

Figure 6. Simulink™ Model for Servo Pneumatic System using PID Control

Position Control of Servo Pneumatic system – using Fuzzy Controller

The theory of control and experimental observation remains the same as described above for the PID controller. In this study a Sugeno-Takagi (TSK) model was used for the rule base to estimate the output voltage. The output voltage is adjusted based on the error and change in error.

Initially a simple model was developed with just the error as a feedback parameter. A total of 5 rules were obtained based on the magnitude of error. Table 1 shows the rule base

Error	LN	SN	Z	SP	LP
Output	LP	SP	Z	SN	LN

Table 1. Rule base for the Fuzzy Controller

Later this system was developed with a fuzzy controller design based on direction and magnitude of error and change in error. A total of 15 rules were obtained based on the above parameters. The following three conditions arise based on error and change in error. When the error is either positive or negative (small or large), and the change in error is zero, the slide is in "stick zone". When the error is small (positive or negative) and the change in error is positive or negative the slide in the slip zone, i.e. we assume that the slide is slipping. When the error is large (positive is negative) and the change in error is positive or negative then the slide is in the "slide zone". Table 2 below illustrates the inference based on error and the change in error.

E **CE**	LN	SN	Z	SP	LP
N	Slide	Slip	Z	Slip	Slide
Z	Stick	Stick	Z	Stick	Stick
P	Slide	Slip	Z	Slip	Slide

Table 2. Inference based on Error & change in Error

Table 3 & Table 4 shows the membership functions for error and change of error. A membership function is defined by a function that maps objects in a domain of concern to their membership value in the set. The membership function provides a smooth transition from regions completely outside a set to regions completely in the set. A parametrizable trapezoidal membership function is used for both error & change in error. The trapezoidal membership function is specified by four parameters.

E	LN	SN	Z	SP	LP

Table 3. Membership functions for error

CE	N	Z	P

Table 4.Membership functions for change in error

Table 5 & 6 illustrates the list of fuzzy variables and the generic fuzzy rule base for the inference arrived in Table 2, based on error and change in error. These output fuzzy singletons are constant functions with a constant voltage and normalization factor associated with each fuzzy variable.

Symbol	**Value**
SP	Small Positive
LP	Large Positive
VLP	Very Large Positive
Z	Zero
VLN	Very Large Negative
LN	Large Negative
SN	Small Negative

Table 5. List of Fuzzy Variables

CE | **E**	LN	SN	Z	SP	LP
N	LP	SP	Z	SN	LN
Z	VLP	VLP	Z	VLN	VLN
P	LP	SP	Z	SN	LN

Table 6. Fuzzy Rule base for the Controller with Error & Change in Error as I/P

The fuzzy scheme was implemented using Simulink™, real time control. The Simulink™ program is shown below in Figure 7. The task was made difficult due to limitations of Simulink™ for real time control. The processing time required for each control loop iteration is very high, thus limiting the sampling frequency. The sampling frequency determines how fast the system can react to change in the output of the servo pneumatic system. A high sampling rate and a fast processing time can reduce the length of "slip" region. A smaller slip region leads to a decreased overshoot and settling time. The values for the singletons are to be tuned experimentally, taking into consideration the limit on the sampling frequency.

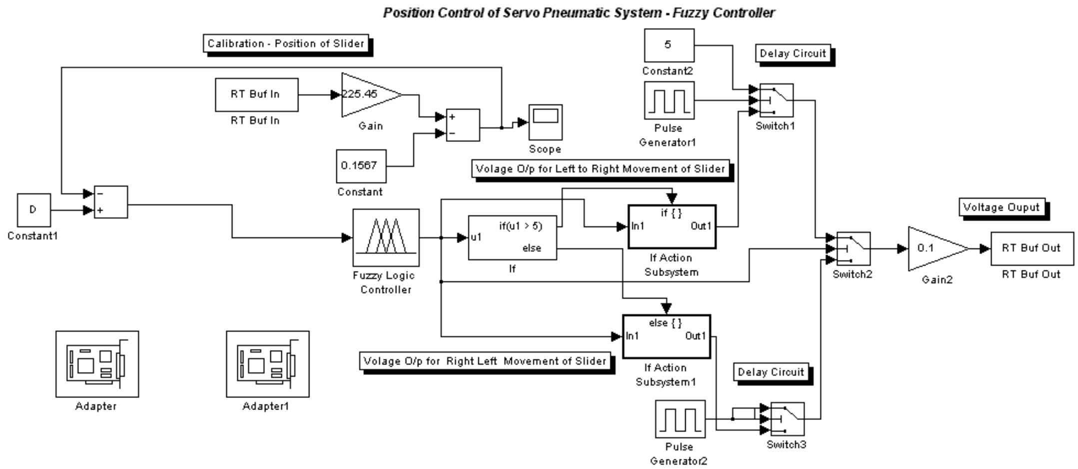

Figure 7. Simulink™ Model for Servo Pneumatic System using Fuzzy Control

Summary

The laboratory modules developed using the Servo pneumatic system help the students in getting to know the concepts of PID and a fuzzy controllers and provide them with the opportunity to gain hands on experience in implementing the similar to real time systems.

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Biographies

Saravanan Rajendran is a Graduate student in the Department of Industrial Engineering at Texas A&M University. He completed his B.S. in 1999 in Mechanical Engineering.

Dr. Bolton is an Assistant Professor in the Manufacturing and Mechanical Engineering Technology Division of the Department of Engineering Technology and Industrial Distribution which is responsible for the technology programs in the Dwight Look College of Engineering at Texas A&M University. Dr Bolton completed his Ph.D. in 1993 in Civil Engineering. His research focus is in experimental mechanics and field investigation of mechanical and civil structural systems. While at Texas A&M Dr. Bolton has taught courses in electromechanical systems, instrumentation and control, mechanics, strength of materials, engineering economy, freshmen engineering, and CADD.