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# To Control Nonlinear Pneumatic System using Fuzzy Logic Controller

Pradeep Rohilla
Mechanical Engineering Department
The NorthCap University
Gurgaon, India

Abhishek Pratap Singh
Mechanical Engineering Department
The NorthCap University
Gurgaon, India

***Abstract*— A system identification technique has been approached to estimate the model of the pneumatic control system. The equal percentage pneumatic control valve makes the system highly nonlinear due to presence of hysteresis and stiction. A classical controller such as PI, PID has been approached but these controllers have limitations to control the nonlinearity presence in the system. A fuzzy controller is applied on the model in Matlab/Simulink environment. The simulated response of classical and fuzzy controller is compared at different operating point. The output response of fuzzy controller is better in term set point tracking and overshoot than conventional controller.**

***Keywords—- Fuzzylogic, pneumatic control valve, hysteresis erro,nonlinear.***

## I. INTRODUCTION

The pneumatic actuators widely used in chemical plants, industrial automation and robotics, because these actuators are cheaper, cleanliness and have limited leakage loss as compared to hydraulic actuator [1].The pneumatic control valve are used to control the flow of liquid or gasses in process industries. The control valves have two parts diaphragm and valve body. The movement of stem controls the flow of fluid in pipe line [2]. During the stem movement static and dynamic frictions are observed. To move the stem from steady state position a considerable amount of force is required. The pneumatic control valve suffer the stiction, dead band and hysteresis error which makes the system highly complex and nonlinear [3].

In the last decade's conventional controller such as P, PI and PID have been implemented in the process industries. The performance of controller is depending upon the tuning parameters of controllers. Ziegler and Nicholas (ZN) proposed the open and closed loop tuning method to obtain the tuning parameters for classical controller. The classical controls have limitation to control the nonlinearity like dead band and hysteresis error in pneumatic valve [4]. To overcome the stiction a stiff proportional derivative (PD) control, is approached [5]. In these the added pulses are filtered by low pass filter, which affect the characteristic of valve, so this techniques are worthless in pneumatic actuators [6]. A linear PI control is used to control the stiction by replace positioners in the control valve are presented by [7]. An accurate tuning of the controller can be reducing oscillation [8]. To obtain the tuning parameters for a time-varying plant become difficult and the corresponding gains of the controller maybe updated online to efficiently control the plant.

To overcome these difficulties a fuzzy logic can be implemented which automatically tune the gains parameters and improves the performance of the plant [9]. [10] Proposed a fuzzy controller in pneumatic servo system which efficiently compensates the cylinder friction effects and air supply pressure to achieve precise load positioning. The pressure inside the boiler used in fossil fuel has been controller by [11]. There are so many researcher those applied the fuzzy pid controller in the real and simulation system. In the present work, fuzzy based controller has been approached to control the nonlinearity such as dead band, hysteresis and stiction in pneumatic valve.

The fuzzy controller gains have been optimized by genetic algorithm techniques in Matlab. Robustness of fuzzy controller is ckecked at different operating point. The methodology, presented in this paper is also capable of handling non-linear processes and has wide industrial applicability.

The paper is organized as follows: Information about experimental setup, Pneumatic control valve's hysteresis error, transducer and system identification are presented in section II. Fuzzy controller with triangular membership functions is provided in the section III. Simulation results of fuzzy and conventional controllers are analyzed in section IV. Lastly, conclusions are given in section V

## II. EXPERIMENTAL SETUP

The snapshot of experimental setup is shown in *Fig. 1*, where compressed air is fed in process tank through valve (V3), which placed at the bottom of the tank and leakage is provided at top of the tank through valve (V5). A pressure sensor is used to measure the pressure in the process tank, which convert the pressure signal into electrical signal in the range of 0-2.5 volts. A low cost USB type National Instruments (NI-6008) Data Acquisition Card (DAQ) has been used for interfacing the experimental system with a computer. The sampling rate is 100 samples per second. The V to I converter, convert the voltage signal into current signal of 4-20 mA. The I to P converter convert the current signal into pressure signal of 3-15psi. This pressure signal is used to control the movement of stem to regulate the pressure in the process tank. Due to static and dynamic friction in lower region of pneumatic control valve a hysteresis error is occurred in forward and backward movement of stem. The hysteresis error in the pneumatic control valve is shown in *Fig. 2*. This makes

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the system highly complex and nonlinear. So it becomes difficult to control these nonlinearities with conventional controller, so a fuzzy controller has been implemented to optimize the tuning parameters.

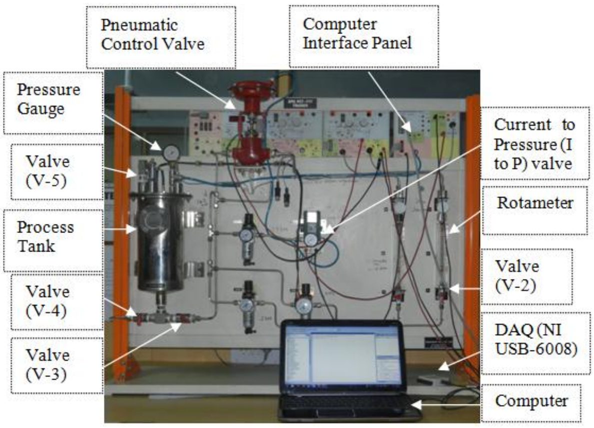


Fig.1: Snapshot of Laboratory Experimental system

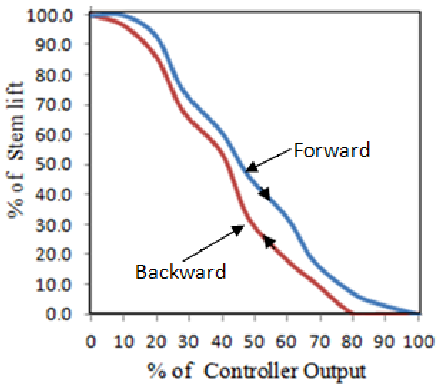


Fig.2: Hysteresis Error in Pneumatic Control Valve

## III. MATHEMATICAL MODEL OF SYSTEM

The mathematical model of the existing system "*Fig.1*" is a cumbersome task by applying the physical laws due to the nonlinearity presents in the system. To overcome these difficulties a system identification method is approached. To estimate the approximate transfer function of the system a step input at 1 bar is provide in system as shown in *Fig. 3*. The data is collected at 100 samples per second and total number is 5000. The input output curve (*Fig. 4*) is used for getting approximate model of existing system as shown below, whereas y(s) is controller output and u(s) is input.

$$\frac{y(s)}{u(s)} = \frac{2.06304s + 1.66991}{3.67155s^2 + 3.8934s + 1}$$

The stability of existing model is determined by knowing the position of poles and zeros in continuous time domain. *Fig. 5* shows that all poles and zeros lie in the negative half plane, so this represents the existing model is stable.

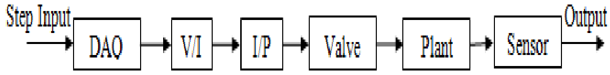


Fig.3: Block diagram of system in open loop

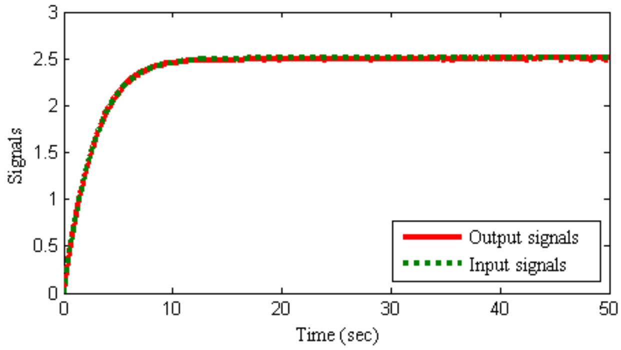


Fig.4: Validation graph

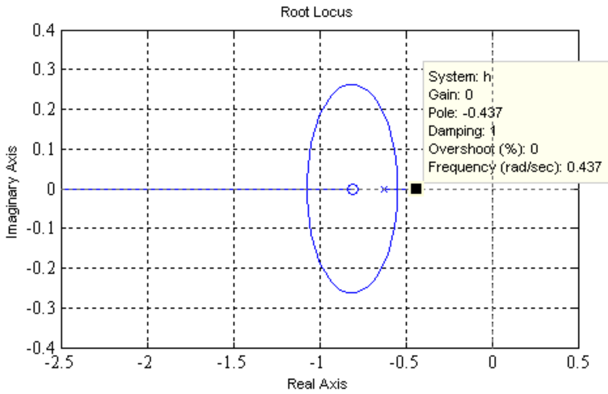


Fig.5: Stability of model

## IV. DESIGN OF FUZZY CONTROLLER

The classical Proportional, Integral and Derivative (PID) controller in time domain can be represented as

$$U_{pid(t)} = K_p e(t) + K_i \int e(t)\,dt + K_d \frac{de}{dt} \quad (1)$$

Where, e(t) is error, Kp, $K_i$, $K_d$ are proportional, integral and derivative gains and Upid (t) is control variable as shown in *Fig. 6*. The performance of controller is depending upon gains parameters.

The classical controllers provide better response at particular operating point but have the limitation when the operating range is changed. These types of controllers have limitation to control nonlinearity such as hysteresis and stiction present in the plant. So, a fuzzy technique is applied which overcome these limitation and provide the better performance at all the operating point. The fuzzy inference mechanism tune gain parameters and generates output control signal.

In fuzzy controller, error (e) and rate of change of error (er) are inputs and $K_p'$, $K_i'$, $K_d'$ are output, whereas K1 and K2 are gain parameters as shown in *Fig.7*. These gain parameters play a vital role in controller performance so a genetic algorithm optimization technique is used to obtain these parameters. The

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value of K1 is 0.45 and K2 is 0.52. It is assumed that $K_p$, $K_i$ and $K_d$ are in prescribed ranges [$K_p$ min , $K_p$ max)], [$K_i$ min , $K_i$ max)], and [$K_d$ min , $K_d$ max)]. The appropriate ranges are determined manually.

$$K_p = K_p \min + (K_p \max - K_p \min) K_p' \quad (2)$$

$$K_i = K_i \min + (K_i \max - K_i \min) K_i' \quad (3)$$

$$K_d = K_d \min + (K_d \max - K_d \min) K_d' \quad (4)$$

The main objective of this study is to minimize overshoot and improve transient response of system. The appropriate range of each parameters are, $K_p \in [20, 0.5]$, $K_i \in [12, 0.05]$, $K_d \in [0.7, 0.05]$.The membership functions for inputs are chosen as triangular (*Fig. 8*) having range from -1 to 1,whereas the input values are shown as Negative Big (NB), Negative(N), Zero (Z), Positive(P) and Positive Big(PB). Whereas outputs membership functions are $K_p$, $K_i$ and $K_d$, these outputs are shown (*Fig. 9*) as Negative Big(NB), Negative(N), Zero (Z), Positive(P) and Positive Big(PB), whereas the ranges from 0 to 1. As per the input and output membership function there 25x3=75 rules. The rules for fuzzy controller are determined by expert experience. The controller rules are design to maintain the pressure at set point having minimum overshoot and quick transient response. The rules are presented in *table1*.

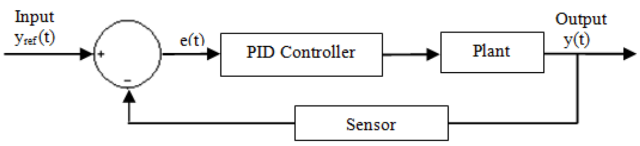


Fig.6: Block diagram of Classical PID Controller

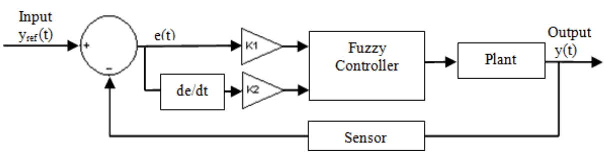


Fig.7: Block diagram of Fuzzy Controller

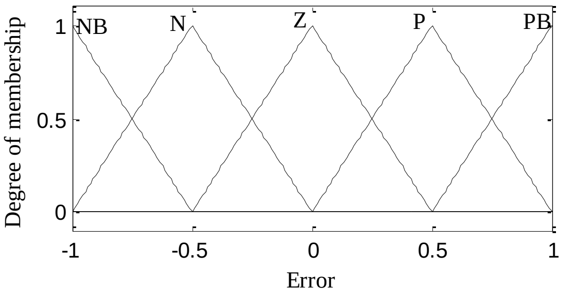


Fig.8: Input MF's of Fuzzy Controller

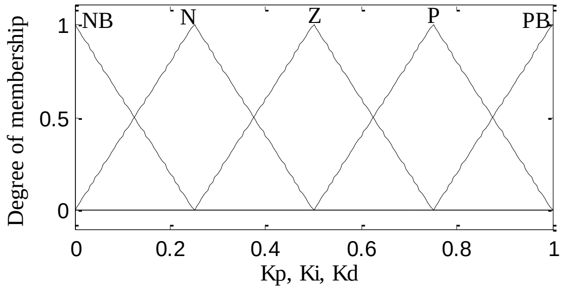


Fig.9. Output MF's of Fuzzy Controller

| **Error** | **Rate of change of error** | | | | |
|---|---|---|---|---|---|
| | **NB** | **N** | **Z** | **P** | **PB** |
| **NB** | PB/NB/P | P/N/NB | P/N/NB | P/N/NB | P/N/NB |
| **N** | P/NB/Z | P/N/N | P/N/N | Z/Z/N | N/P/Z |
| **Z** | P/N/Z | P/N/N | Z/Z/N | N/P/N | N/P/Z |
| **P** | P/N/Z | Z/Z/Z | N/P/Z | N/P/Z | N/PB/Z |
| **PB** | Z/Z/PB | N/P/P | N/P/P | N/P/P | NB/BP/PB |

TABLE 1. Rules for Kp, Ki, Kd

## V. SIMULATION RESULT AND DISCUSSION

In this section, the simulation result of classical controller is compared with fuzzy controller at different operating point in Matlab/simulink environment. The step signals of 0.5, 1, 1.5 bar is given as input. The sampling rate is 100 samples per sec and Range Kutta is an ordinary differential solver. The performance of the controller at different operating point is shown in *Fig.* (10-14). The mathematical model has been obtained at set value of 1 bar. All the gain parameters have been obtained at set value of 1 bar and same is applied to other operating point. These tuning parameter of conventional pid controller and fuzzy controller are applied at different operating point. *Fig. 10* shows the output response at set point 1bar, the response of classical controller having rise time = 0.8 sec, settling time = 5 sec, overshoot = 28.57% and fuzzy controller have rise time = 0.65 sec, settling time = 2 sec overshoot = 1.96%. The output response at set point 1.5 bar is shown in *Fig 11*, whereas the response of classical controller having rise time =1.3 sec, settling time =5.5 sec, overshoot = 38.02% and fuzzy controller have rise time =0.60 sec, settling time = 2 sec, overshoot = 1.96 %. *Fig 12*, represents the output response at set point 0.5 bar , the response of classical controller having rise time =0.4 sec, settling time = 3 sec overshoot=18.03% and fuzzy controller have rise time = 0.7 sec, settling time = 1.5 sec overshoot=1.96%. The output response at different operating points has been tested as shown in *Fig.13*.The output response of classical and fuzzy controller are compared and result shows that fuzzy controller have better response in term transient response and having no overshoot at set point. The simulations results represent the fuzzy controller tracks the set point without oscillation and overshoot.

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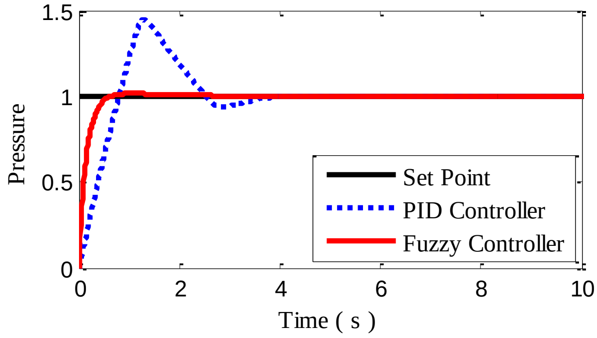


Fig.10: Process output at set pressure of 1 bar

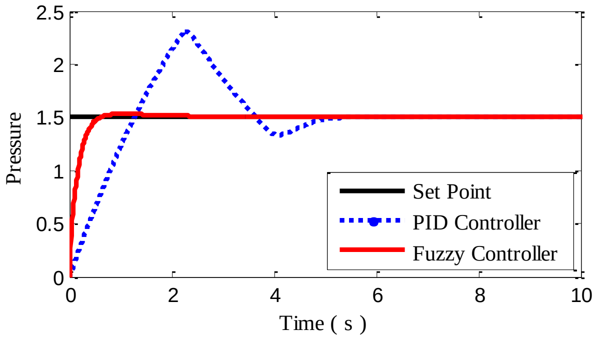


Fig.11: Process output at set pressure of 1.5 bars

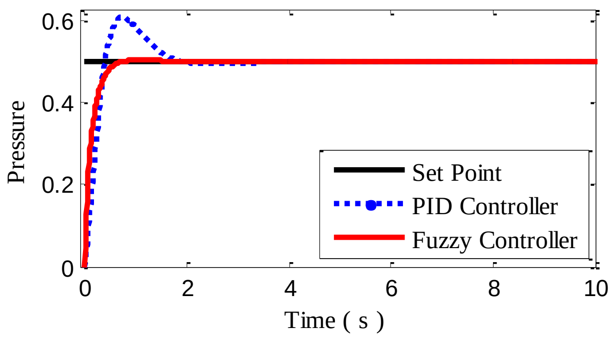


Fig.12: Process output at set pressure of 0.5 bars

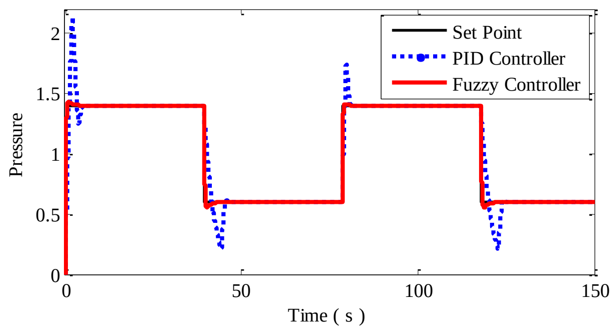


Fig.13: Output response at different operating points

## VI. CONCLUSION

The system identification toolbox in Matlab/Simulink is used to obtain the mathematical model of the experimental system. The simulation results represents that fuzzy controller provide an adequate performance at set point tracking and minimize the overshoot. The result shows that designed controller performance is superior to classical controller.

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