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Analysis of a Fuzzy Self Tuning PID Controller for Nonlinear Pressure Control System.

Pardeep Rohilla
Mechanical Engineering Department
ITM University
Gurgaon, India

Abhishek Pratap Singh
Mechanical Engineering Department
ITM University
Gurgaon, India

***Abstract*—Pneumatics actuator play a vital role to control the pressure in industries. A lot of research has been conducted to control the nonlinear characteristics of pneumatic control valve. A fuzzy logic based self tuning pid controller has been approached to control the nonlinearity such as hysteresis, stiction in pneumatic control valve. The fuzzy pid controller has been applied in the simulation in Matlab environment. The simulation results show that the fuzzy pid controller is superior than the conventional controller.**

Keywords-Intelligent controller, Fuzzylogic, pneumatic control valve, hysteresis error.

I. INTRODUCTION

The application of pneumatic actuation is very common in industries because these actuators are cheaper, cleanliness and have limited leakage loss as compared to hydraulic actuator. These are extensively used in manufacturing, robotic and industrial automation [1]. The pneumatic control valve are used as an actuator to control the flow in the process industries. The control valves have mainly two parts diaphragm and valve body. Diaphragm is used as an actuator which converts the pressure signal into the displacement in the form stem movement with plug assembly. The plug assembly, further consist of plug and plug sheet, which control the flow of compressed air through the pipe line [2]. In these type of control valve a significant amount of force is required to move the stem from a steady state condition. An accurate valve positioning is required for position control in the system; the varying differential pressures cause the plug position to vary. The static and dynamic frictions are observed during the stem movement in the control valve. Static friction is the friction when the body is stationary and dynamic friction is the friction when there is movement in the body. The influence of static friction is higher than the dynamic friction so that an enormous force is required to move the stem from steady state position. There are so many researchers who gave the definition of stiction and the one expressed clearly by (choudhury 2005) which replicate the physical behavior of the stiction." Stiction is a property of elements such that its movement in response to a varying input is preceded by a staticpart (deadband plus stickband) followed by a sudden abrupt jump called slip-jump. Its origin in a mechanical system is static friction which exceeds the friction during smooth movement"[3]. The pneumatic control valve suffer the stiction, dead band so that its input output characteristic show highly nonlinear behavior. There is a friction especially in the packing which causes the unacceptable hysteresis error in the control valve.

The conventional Controller (PID) has been widely used in the process industries. The tuning parameters of controllers are crucial for the constructive performance of the plant and are very useful from the operator's point of view. Ziegler and Nicholas(ZN) proposed the open and closed loop tuning method to obtain the tuning parameters for classical controller. ZN have limitation to control the nonlinear system having stiction, hysteresis error in the pneumatic control valve [4]. The various method have been developed to overcome the stiction such as PD compensation methods to overcome stiction in machines, such as stiff proportional derivative(PD) control, PD with integral control with dead band, dithering and impulsive control techniques were discussed [5]. The added pulses are generally filtered by low pass characteristic of pneumatic actuators making these techniques ineffective in pneumatic control valve [6]. A control scheme for stiction in pneumatic control valve to replace positioners using linear PI control is presented by [7]. Through proper controller tuning the amplitude and frequency of stiction related oscillation can be reduced on the basis of describing function analysis is presented by [8].

A time-varying plant can be approximated at various instants of time and the corresponding gains of the controller maybe updated online to efficiently control the plant. This method is commonly a form of adaptive control known as gain scheduling of PID controllers and is widely used in the process industries as an effective means to compensate for variations in process parameters overshoot and settling time.
Fuzzy logic is knowledge based systems which automate the operator task by adjusting the tuning parameters which influence the performance of the system [9]. The fuzzy controllers are simple and easy to implement and smooth behavior. [10] proposed a fuzzy pid gain scheduling controller for the compensation of cylinder friction effects and air supply pressure variations in a pneumatic servo system in order to achieve precise load positioning. [11] uses a fuzzy PID controller for power stabilization in a superconducting magnetic energy storage. The pressure inside the boiler used in fossil fuel has been controller by [12]. There are so many researcher those applied the fuzzy pid controller in the real and simulation system. In the present work, fuzzy gain scheduling controller has been approached to control the

nonlinearity such as stiction, hysteresis in the pneumatic control valve.

A fuzzy gain scheduling has been trained off-line to simulate the experimental non-linear process. The corresponding gains of the PID controller for different process parameters are obtained using an fuzzy based approach and are scheduled considering the processes to be time varying in nature. The methodology, presented in this paper is also capable of handling non-linear processes and have 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 PI controller with Gaussian membership functions is provided in the section III. Experimental results of Intelligent and conventional controllers are analyzed in section IV. Lastly, conclusions are given in section V

II. EXPERIMNETAL SETUP

The experimental setup consists of a process tank as shown in Fig.1, where the compressed air is fed through a manually operated control valve (V3), having size of 15mm placed at the bottom of the tank . A manually operated valve (V5) is provided at the top of the tank, that can be used to maintain a constant rate of air flow. The Pressure inside the process tank is measured by a piezo-resistive transducer(SX30DN), which convert the pressure signal into electrical signal in the range of 0-2.5 volts. The pressure inside the process tank having the range of 0 to 2 bar. It is calibrated with the help of a Pressure dial gauge . When the Pressure at 0 bar the output voltage is 0 volts and at 2 bar the output voltage is 2.5 volts. A National Instruments (NI-6008) Data Acquisition Card (DAQ) has been used for interfacing the experimental system with a computer. It is low cost USB type DAQ card having 08 analog input and 08 digital out channel. 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, converts the current signal into pressure signal of 3-15psi. This pressure signal is used to control the movement of pneumatic control value stem to regulate the pressure in the process tank. There is an friction between stem and packing of pneumatic control valve which makes an hysteresis error during the forward and backward movement. In lower region nonlinearity in the plant has been marked due to the influence of friction, hysteresis, deadzone in the control value. The hysteresis error in the pneumatic control valve is shown in Fig 2. This makes the system highly complex and nonlinear. So it become difficult to control these nonlinearities with conventional controller, so an intelligent technique (fuzzy logic) is used to optimize the tuning parameters of PID controller and makes the adaptive control of the system.

III. MODEL ESTIMATION

A system identification technique has been used for model estimation of pressure control system as shown in Fig 1. The system is considered as an open loop and a step input is applied to obtain the transfer function. Data for model estimation is taken at rate of 100 sample per second. The input

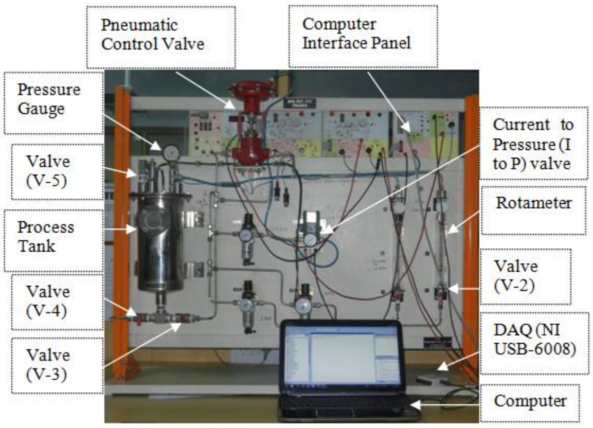

Fig.1. Snapshot of Laboratory Experimental system

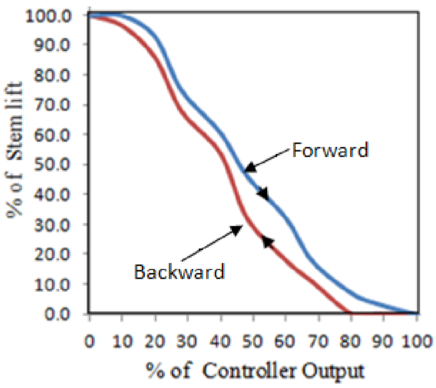

Fig.2. Hysteresis Error in Pneumatic Control Valve

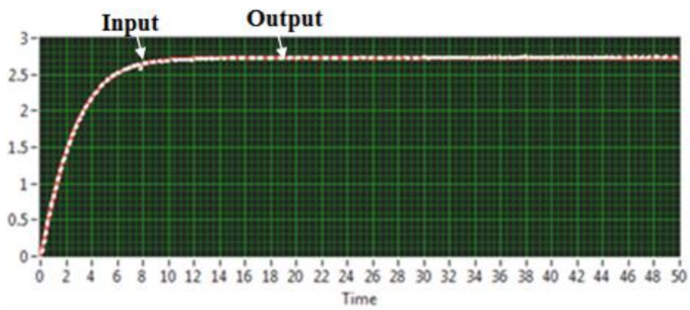

Fig.3. Input –Output Graph for Model Estimation

output data have been taken and a graph has been plotted between these data as shown in Fig 3. The continuous line represented the input data and dotted line form output data, whereas the output is overlapping with the input. Based on the output model curve the transfer function is obtained by using System Identification Toolbox in Labview Software. The estimated model of the experimental system is given below, where as y(s) & u(s) represents the output and input.

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$$y(s) = \frac{0.409644 + 367.854s}{1 + 273.477s + 625.029s^2} u(s)$$

IV. DESIGN OF FUZZY PID CONTROLLER

The PID controllers have been applied in the process industries because of its ease design and simple control structure. The classical PID controller can be expressed in the time domain as

$$Upid(t) = K_p e(t) + K_i \int e(t)\, dt + K_d \qquad (1)$$

Where, Upid(t) is the controller output. e(t) is the error in the control system and K_p, K_i, K_d are Proportional, Integral and Derivative gains of the PID control system.

$$e(t) = y_{ref}(t) - y(t) \qquad (2)$$

where, the y_{ref} is the desired output and y(t) is the actual output of the plant. The performance and robustness of the system is depending upon the tuning parameters of PID Controller. These controllers gave the good response at the fixed operating range but have the limitation when the operating range is changed. The performance of the controller is not satisfactory for nonlinear system. An intelligent technique is required to tune the parameters of PID Controller. So, fuzzy logic technique has been used for tuning the parameters of the PID controller.
The fuzzy inference system is used for tuning the three gain parameters K_p, K_i and K_d, then output control signal is generates by PID controller as shown in Fig 4.

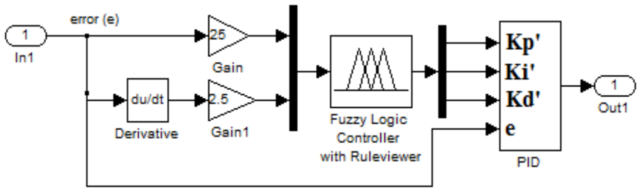


Fig. 4 Fuzzy PID controller model

Error(e) and rate of change of error (er) are the input of fuzzy controller and K_p', K_i', K_d' are the tuning parameters of PID controller which is obtained by Fuzzy knowledge. In this study the performance of index is to minimize the overshoot and steady state error in the process tank. 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 experimentally and will be given in equation as shown below.

$$K_p = K_p \min + (K_p \max - K_p \min) K_p' \qquad (3)$$

$$K_i = K_i \min + (K_i \max - K_i \min) K_i' \qquad (4)$$

$$K_d = K_d \min + (K_d \max - K_d \min) K_d \qquad (5)$$

The ample range of K_p, K_i and K_d have been obtained by Genetic Algorithm(GA) optimization technique as shown in table 1. These parameters are obtained offline having performance of index is integral time absolute error (ITAE).

Table 1 PID Gain Parameters

Gain Parameters	Min	Max
K_p	70	16
K_i	30	19
K_d	1	0.015

The GA obtained value from table 1are put in equations (3, 4 & 5) and the initial parameters K_p', K_i' and K_d' are obtained through the Fuzzy logic algorithm.

$$K_p = 54\, K_p' + 16 \qquad (6)$$

$$K_i = 11\, K_i' + 19 \qquad (7)$$

$$K_d = 0.985\, K_d' + 0.015 \qquad (8)$$

The fuzzy obtained pid parameters K_p', K_i' and K_d' are applied to the system for controlling the pressure without overshoot and steady state error.

A. Control Rule

In fuzzy set domain, each universe of discourse are selected to be seven fuzzy set ranging from negative side to positive side i.e. error(e) and rate of change of error (er) from [-1,1] with the gaussian membership function as shown in Fig 5. The pid parameters K_p, K_i, K_d are defined as [0,1] with the gaussian membership function as shown in Fig 6. The NB, NM, NS, ZO, PS, PM, PB are linguistic variable of fuzzy set, where NB, NM, NS, ZO, PS, PM, PB stands for Negative Big, Negative medium, Negative small, Zero, Positive small Positive Medium, Positive Big. In the present work, mamdani inference mechanism has been used because of simple min-max structure and for defuzzification centroid method is used.

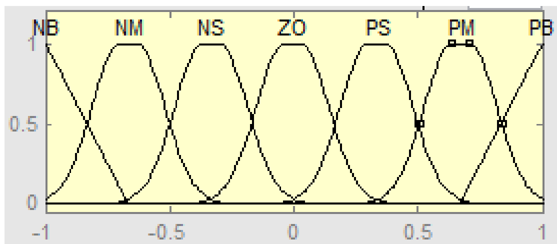


Fig. 5 Membership Function for e and er

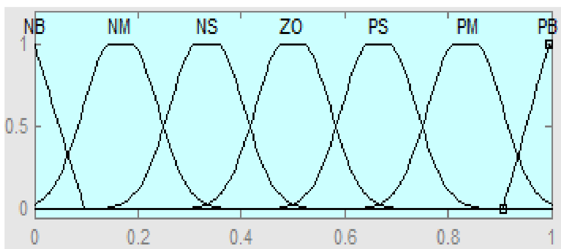


Fig. 6 Membership Function for K_p', K_i', K_d'

According to the number of input and output membership function the fuzzy pid controller have 49x3 =147 rules as shown in table 2. The fuzzy rule of K_p, K_i and K_d are established on the basis of expert experience.

The fuzzy rule are described as

If e is A and er is B then K_p' is C, K_i' is D and K_d' is E, where e is the error and er rate of change of error and C, D, E are the fuzzy gain parameters of pid controller.

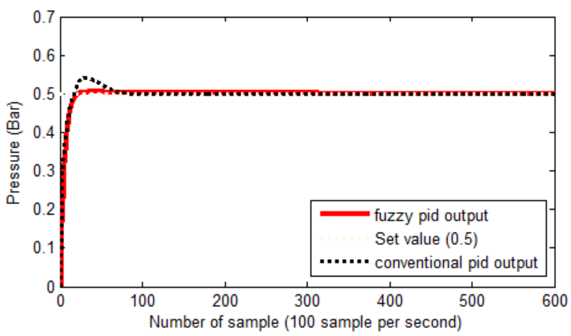
For example if error is NB and er is NB then K_p is PB, K_i is NB and K_d is PS similar other rules are formed as shown in table2. The fuzzy control rules are design on the basis of pneumatic control value to maintain the pressure inside the process tank at set level without overshoot and having fast response.

Table 2 Fuzzy rule for K_p', K_i', K_d'

er / e	NB	NM	NS	ZO	PS	PM	PB
NB	PB/ NB /PS	PB/ NB/ NS	PM/ NM/ NB	PM/ NM/ NB	PS/ NS/ NB	ZO/ ZO/ NM	ZO/ ZO/ PS
NM	PB/ NB/ PS	PB/ NB/ NS	PM/ NM/ NB	PS/ NS/ NM	PS/ NS/ NM	ZO/ ZO/ NS	NS/ ZO/ PS
NS	PM/ NB/ ZO	PM/ NM/ NS	PM/ NS/ NM	PS/ NS/ NM	ZO/ ZO/ NS	NS/ PS/ NS	NS/ PS/ ZO
ZO	PM/ NM/ ZO	PM /NM/ NS	PS/ NS/ NS	ZO/ ZO/ NS	NS/ PS/ NS	NM/ PM/ NS	NM/ PM/ ZO
PS	PS/ NM/ ZO	PS/ NS /ZO	ZO/ ZO /ZO	NS/ PS/ ZO	NS/ PS/ ZO	NM/ PM/ ZO	NM/ PB/ ZO
PM	PS/ ZO/ PB	ZO/ ZO/ NS	NS/ PS/ PS	NM/ PS/ PS	NM/ PM/ PS	NM/ PB/ PS	NB/ PB/ PB
PB	ZO/ ZO/ PB	ZO/ ZO/ PM	NM/ PS/ PM	NM/ PM/ PM	NM/ PM/ PS	NB/ PB/ PS	NB/ PB/ PB

V. SIMULATION RESULT & DISCUSSION

The Conventional and fuzzy pid controller at different operating point have been applied in Matlab/simulink environment. The input is given in the form step signals of 0.5, 1, 1.5. GA optimization technique has been applied for getting the gain parameters of conventional PID controller. The tuning has been done offline in Matlab/Simulation software. The simulation operating parameters have sampling time 0.01 second and ordinary differential solver is ODE4 (Runge Kutta). The performance of index(PI) is Integral Time Absolute Error(ITAE). The tuning parameter of conventional pid controller are; K_p=36 , K_i=180, K_d =1.8
The reference pressure is set to 0.5 bar and 1 bar. At set pressure of 0.5 bar, the response of conventional controller having rise time =0.16 sec, settling time =02 sec



overshoot=8.25% and fuzzy self tuning controller have rise =0.18sec, and no overshoot as shown in Fig 7 .

Fig. 7. Response of two controller at reference pressure of 0.5 bar

At set pressure of 1 bar, the response of conventional controller having rise time =0.16 sec, settling time 03sec , overshoot=8.5% and fuzzy self tuning controller have rise =0.21 sec and no overshoot is observed as shown in Fig 8.

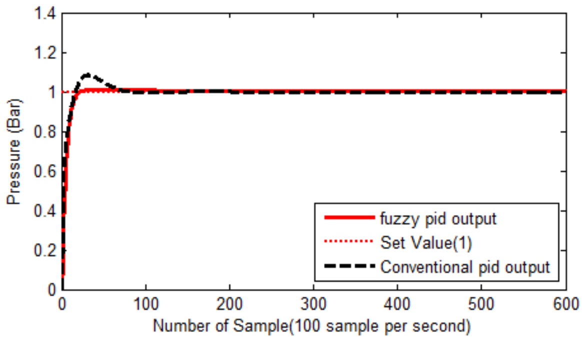


Fig. 8. Response of two controller at reference pressure of 1 bar

The response of conventional pid and fuzzy self tuning pid controller are compared and result shows that fuzzy self tuning pid controller have no overshoot, faster rise time and has better dynamic response without steady state error.

VI. CONCLUSIONS

The mathematical model of the experimental Pressure control unit and fuzzy self tuning pid controller has been designed in the Matlab/simulink software. The simulations results show that fuzzy self tuning pid controller are superior in terms of stability and fast response. It shows that the designed controller performance is better than conventional controller.

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