



Design of an Intelligent Pressure Control System Based on the Fuzzy Self-tuning PID Controller

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Abstract— A method for tuning of conventional PID controller based on the Fuzzy logic for regulating pressure in a pilot pressure control system has been presented in this article. Recently, it has been noticed that PID controllers are often poorly tuned and some efforts have been made to systematically resolve this matter. In the proposed structure an intelligent fuzzy controller has been designed in such a way to adjust the parameters of a classical PID controller in on-line that will reduce the human involvement in tuning the controller parameters at different operating conditions. The pressure process model has been obtained through experimental study by the methods of Cohen-Coon rule based PID control. Fuzzy logic is used to tune each parameter of PID controller. Through simulation in Matlab by selecting appropriate fuzzy rules are designed to tune the parameters K_p , K_i and K_d of the PID controller, the performance of the pressure controlled system has improved significantly compare to conventional PID controller.

Keywords — Pressure control, Self-Tuning, Fuzzy PID, Matlab, Simulink

I. INTRODUCTION

Pressure control is very common in steam generation of industrial power plants, reaction control in chemical industry, heating, ventilating and air conditioning (HVAC) system and Mobile hydraulic applications. In the 1990s, scientists and researchers were trying to use intelligent techniques, such as, fuzzy logic, to enhance the capabilities of classical PID controllers and their family. They were trying to combine fuzzy logic control technology with a conventional PID controller to obtain behavior similar to that of a regular PID controller. It is thus believed that by combining these two techniques together a better control system can be achieved.

The majority of the research work on fuzzy PID controllers focuses on the conventional two-input PI or PD type controller proposed by Mamdani. This paper mainly focuses on designing the new fuzzy self-tuning PID algorithm in order to control pressure. The purpose is to improve the performance of the system and decrease the pressure fluctuation[1, 2].

The outline of the paper is as follows: the pressure process model of the system is presented in Section II.

The design of fuzzy self-tuning PID controller is provided in Section III. Simulation results on analysis of the algorithms are presented in Section IV. Finally, concluding remarks are made in Section V. Simulation results illustrate the effectiveness of the proposed method.

II. CASE STUDY - PRESSURE PROCESS CONTROL LOOP

The experimental setup of pressure control system and its representation are shown in Figs.1 and 2, respectively. The system includes pressure tank from 0 to 4 bars, AFR3 in series with Rotameter R1, Flow sensor FS1, pneumatic valve, V/I and I/P converters, all connected in series. The pressure sensor (0 to 60 PSI) is mounted inside the computer interface panel (CIP). A blue colored Polyurethane tube taps the pressure of process tank and is straight brought in to CIP panel to be coupled to sensor port (P1). The output of the sensor is brought to signal conditioning circuit in CE2 panel using 3 pin DIN connector.

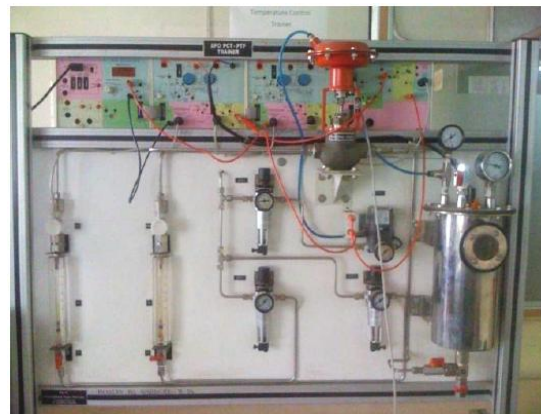


Figure 1. Process Control Trainer

The capacity of the vessel is 5 Kg/cm² and the relief valve opens when the pressure exceeds its maximum capacity. The load disturbance can be applied using the vent valve (V5). The pneumatic pressure of 0- 8 bar is received from compressor via regulator (ARF1) is applied to the I/P converter as a source pressure. The pneumatic control valve is direct or reverses acting and

operates on 3 to 15 psi, that is, remains fully open if the pressure is 3 psi and full closed if the pressure is 15 psi.

In this system, process variable or CV is pressure in the vessel and manipulated variable is pneumatic flow through the control valve via ARF2. Pressure sensor and transmitter is mounted on top of the vessel and transmits 4-20 mA signal correspond to 0 to 5 Kg/cm² pressure. The 4 to 20 mA current signal converted into 0 to 5 V voltage signal and transmitted to the PC through CIP card. Since all elements in this system are of the first order with small time constant and delay time, it is a type zero and conditionally stable system.

Pressure process variable is fast changing hence the pressure process goes from one steady state to another steady state within short time. Also pressure oscillates with very small amplitude. Thus if we give larger gain values in PID action then pressure variations may become oscillatory.

The Cohen-Coon-open-loop process reaction curve method for the 50 percent of inlet control valve opening has been used to obtain the model of pressure control process [3].

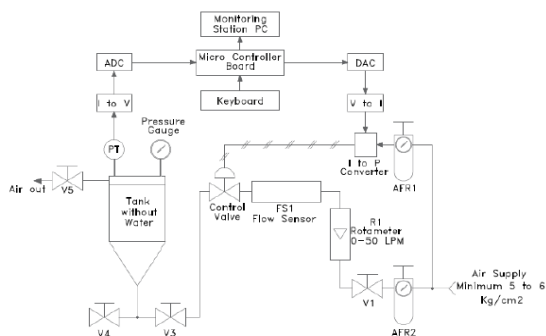


Figure 2. Block diagram of Pressure control Loop

The system transfer function is approximated into a first order with dead time process which is given as

$$G_P(s) = \frac{K_p e^{-T_d s}}{T s + 1} \quad \dots \text{Eq. (1)}$$

The parameters of Eq. (1) were estimated using C-C controller tuning and the values are given in Table 1.

Table 1. Parameters of the Pressure regulating system

Valve opening in %	Process gain (Kp)	Time constant (T) Sec.	Dead time (Td) Sec.
50%	9.2	85.5	1.6

The identified continuous time system with transfer function of Pressure Control system is

$$G_P(s) = \frac{9.2 e^{-1.6s}}{85.5s + 1} \quad \dots \text{Eq. (2)}$$

III. THE DESIGN OF FUZZY SELF-TUNING PID CONTROLLER

A. Structure of Self-Tuning Fuzzy PID Controller

Self-tuning fuzzy PID controller means that the three parameters K_p, K_i and K_d of PID controller are tuned by using fuzzy tuner [4]. The coefficients of the conventional PID controller are not often properly tuned for the nonlinear plant with unpredictable parameter variations. Hence, it is necessary to automatically tune the PID parameters. The structure of the self-tuning fuzzy PID controller is shown in Fig.3.

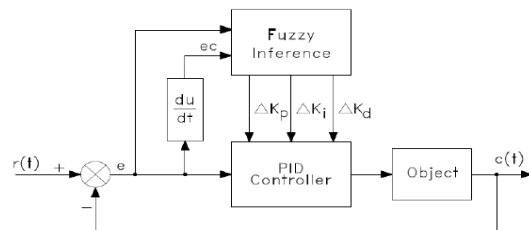


Figure 3. Structure of self tuning fuzzy PID controller

The new fuzzy-PID controller takes conventional PID as the foundation, which uses the theory of fuzzy reason and variable discourse of universe to on-line regulate the parameters of PID automatically. From the Fig.3 we can get that the error and error changing rate are used as the input variables in the controller, and the output variables are the parameters of PID control, those are ΔK_p, ΔK_i and ΔK_d. Here, e denotes the system error; ec denotes the system error changing rate.

B. Design of Self-Tuning Fuzzy PID Controller

The rules designed are based on the characteristic of the pressure control loop and properties of the PID controller. Therefore, the fuzzy reasoning of fuzzy sets of outputs is gained by aggregation operation of fuzzy sets inputs and the designed fuzzy rules. The aggregation and defuzzification method are used respectively max-min and centroid method.

Regarding to the fuzzy structure, there are two inputs to fuzzy inference: error e(t) and derivative of error de(t), and three outputs for each PID controller parameters respectively K_p, K_i and K_d. Mamdani model is applied as structure of fuzzy inference with some modification to obtain the best value for K_p, K_i and K_d.

Fuzzy inference block of the controller design is shown in Fig. 4 below.

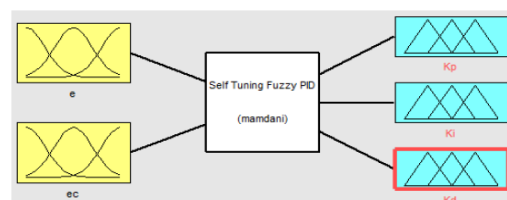


Figure 4. Fuzzy inference block

Suppose the variable ranges of the parameters K_p , K_i and K_d of PID controller are respectively (K_p min, K_p max), (K_i min, K_i max), and (K_d min, K_d max).The range of each parameter was determined based on the simulation on PID controller to obtain a feasible rule bases with high inference efficiency. The range of each parameters are, $K_p \in (6,15)$, $K_i \in (1.5,4)$ and $K_d \in (3, 4.5)$. Therefore, they can be calibrated over the interval (0, 1).

Hence, we obtain:

$$K_p = 9K_p' + 6, K_i = 2.5K_i' + 1.5, \text{ and } K_d = 1.5K_d' + 3.$$

The membership functions of these inputs fuzzy sets are shown in Fig.5 and Fig.6.

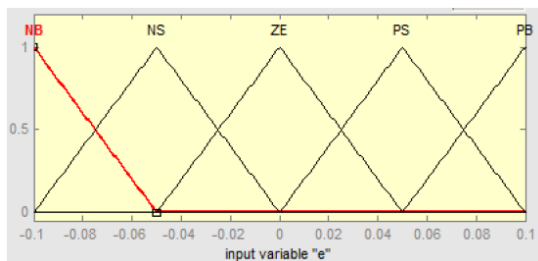


Figure 5. Membership functions of $e(t)$

The linguistic variable levels are assigned as NB: negative big; NS: negative small; ZE: zero; PS: positive small; PB: positive big. These levels are chosen from the characteristics and specification of the pressure control system.

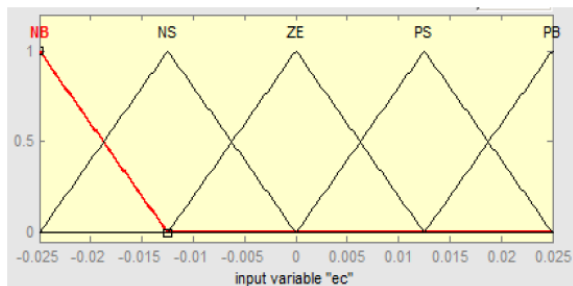


Figure 6. Membership functions of $de(t)$

The ranges of these inputs are between -0.1 to 0.1, which are obtained from the absolute value of the system error and its derivative through the gains.

Whereas the membership functions of outputs K_p' , K_i' and K_d' , are shown in Fig. 7.

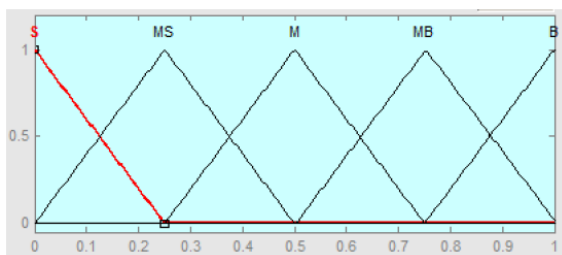


Figure 7. Membership functions of K_p' , K_i' and K_d'

The linguistic levels of these outputs are assigned as S: small; MS: medium small; M: medium; MB: medium big; B: big, where the ranges from 0 to 1. Generally, the fuzzy rules are depended on the plant to be controlled and the type of the controller and from practical experience. Regarding to the above fuzzy sets of the inputs and outputs variables, the fuzzy rules are perform in rules table as shown in Fig. 8 and composed as follows:

Rule i: If $e(t)$ is $A1_i$ and $de(t)$ $A2_i$ then $K_p' = B_i$ and $K_i' = C_i$ and $K_d' = D_i$.

Where $i= 1, 2, 3... n$, and n is number of rules. From the table, since we have 5 variables as input and 5 variables as output, hence, in the design we have 25 fuzzy rules.

De/e	NB	NS	ZE	PS	PB
NB	S	S	MS	MS	M
NS	S	MS	MS	M	MB
ZE	MS	MS	M	MB	MB
PS	MS	M	MB	MB	B
PB	M	MB	MB	B	B

Figure 8. Rules of the fuzzy inference

IV. RESULTS AND DISCUSSION

Self-tuning fuzzy PID regulator subsystem block as shown in Fig. 9 consists of Fuzzy and PID block with some modification refers to the formula which is applied to calibrate the value of K_p' , K_i' and K_d' from fuzzy block to obtain the value of K_p , K_i and K_d . Each parameter has it's own calibration [5, 6]. While, the complete Simulink block for whole system including the control design and the plant is shown in Fig. 10.

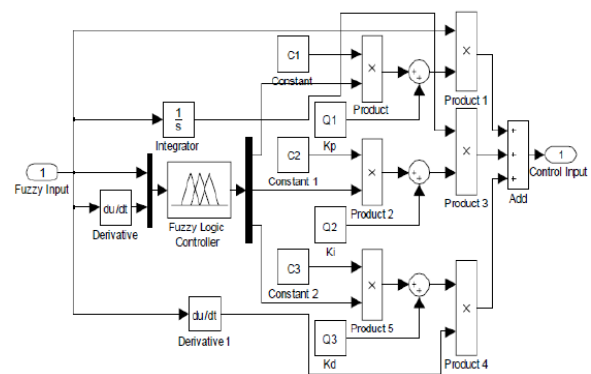


Figure 9. Simulink Block of Fuzzy PID regulator for pressure control.

The value of parameter K_p , K_i and K_d are tuned by using signals from fuzzy logic block based on the changes in the error between reference signals and output signals. The simulated output response of the self tuning fuzzy-PID controller is presented for the set pressure of 2 bar and 3 bar and is shown in Fig.11. From

the response it is observed that the classical PID controller takes reasonable time to settle tank pressure at set level. On the other hand, the self tuning fuzzy-PID controller output settles quicker without any overshoot and oscillation.

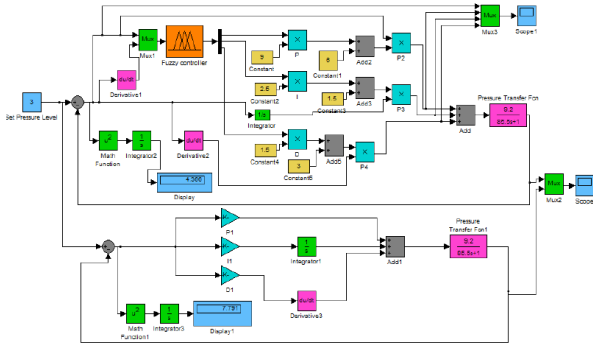
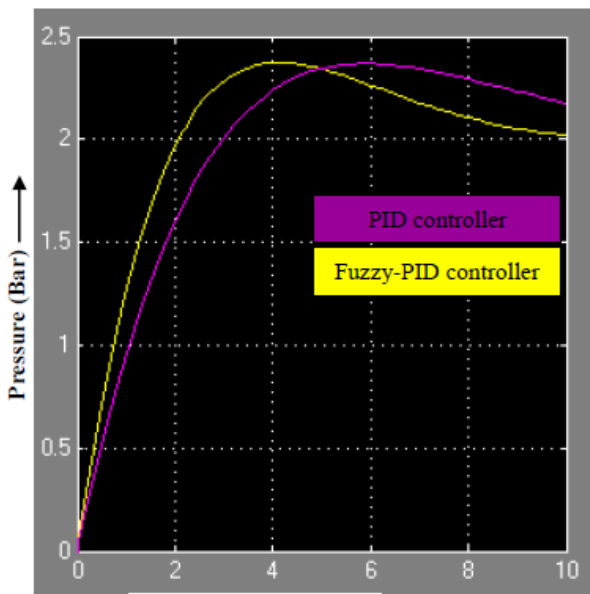
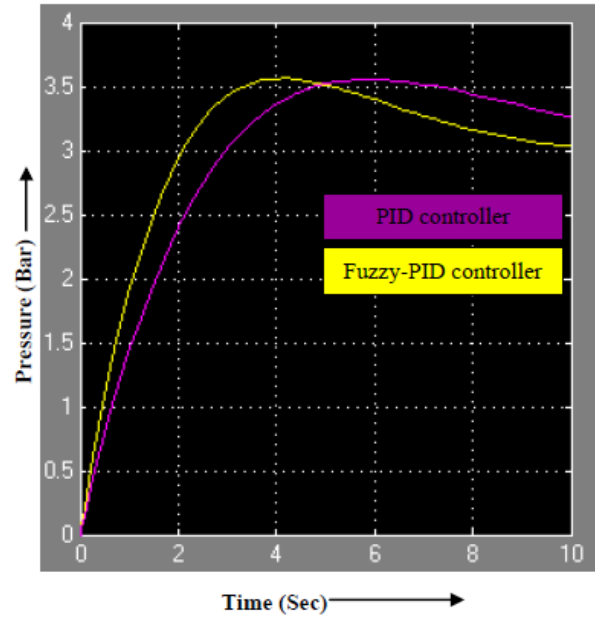


Figure 10. Simulink Block of the Pressure system and Fuzzy PID controller

The online variation of the proportional and integral scaling factor with respect to error scaling factor with respect to error has been studied through simulation and is shown in Fig.12



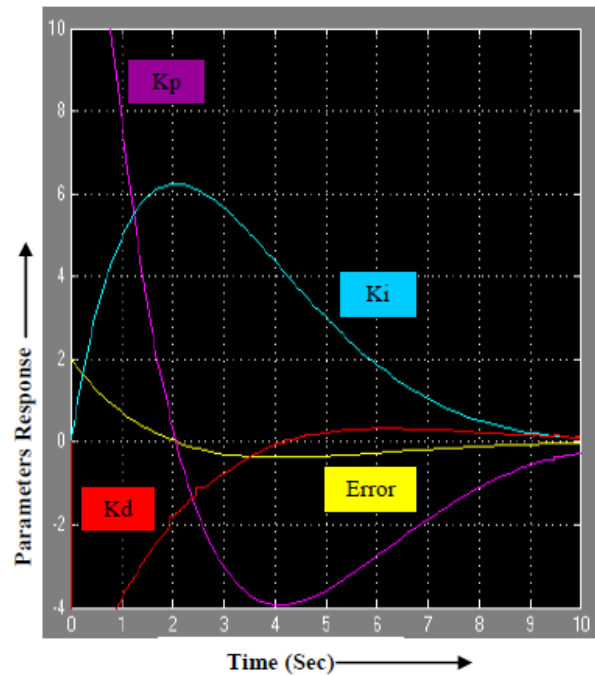
(a) set pressure of 2 bar



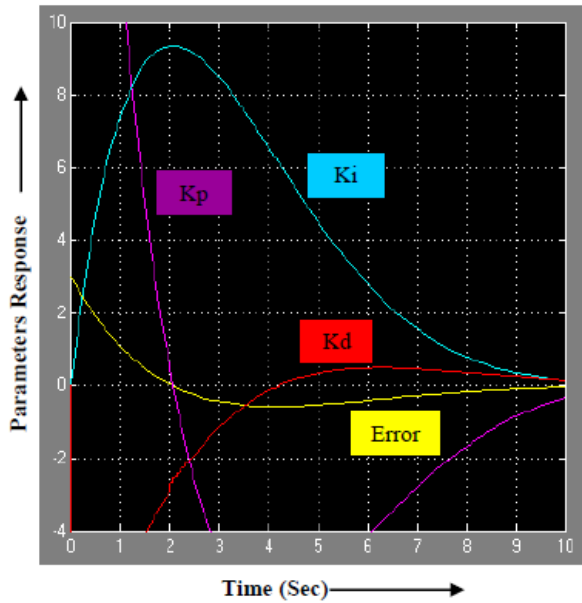
(b) set pressure of 3 bar

Figure 11. Simulated output response of the pressure control system

It is observed that the value of the proportional gain is varying with large amount, but the integral gain variation is found to be very small.



(a) set pressure of 2 bar



(b) set pressure of 3 bar

Figure 12. Parameters variation in hybrid fuzzy-PID controller

Table 2. Controllers performance comparison in terms of ISE

Type of Controller	ISE for 2 Bar	ISE for 3 Bar
PID	3.48	7.79
Fuzzy PID	2.48	4.36

The performance comparison of the proposed controller with classical PID controller by using the error criteria is given in Table 2. From this comparison the Self tuning fuzzy PID controller proved to be superior to classical PID controller. The responses of the proposed control design look satisfied. However, the proposed control needs to develop by including disturbance and any others nonlinearity and uncertainties in the design with various frequencies in reference input signals.

V. CONCLUSION

The on-line scaling factor modification of the PID controller by using an intelligent self tuning fuzzy PID



control technique appears superior to the conventional PID controller for pressure control process. The adaptation of fuzzy mechanism to tune the classical controller for setpoint variations is a suitable and easier method and it will be applicable to all type of real-time complex process. Self-tuning fuzzy controller was applied to tune the value of K_p , K_i and K_d of the PID controller. Through some tests on the system by using step input signals. The system responses indicate the performance of the pressure control system was improved and satisfied compare to conventional PID controller.

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