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Design of Self-Tuning Fuzzy PI controller in LABVIEW for Control of a Real Time Process

A.K.Pal [1] , I.Naskar [2]
[1 2] Department of Applied Electronics and Instrumentation Engineering
[12] Heritage Institute of Technology
[1] Email- arabindakumarpal@gmail.com
[2] Email- indrajit.naskar@heritageit.edu

Abstract- Pressure control systems constitute the heart of many process plants. Linguistic modeling and decision-making processes like fuzzy and neural controller are very much useful to control the complicated processes. An intelligent control strategy has been proposed and successfully applied to a real time water pressure control system. For the variation of set point change and load disturbance, an intelligent control scheme has been developed by integrating self-tuning scheme with fuzzy PI controller. Satisfactory industrial application results show that such a control scheme has enhanced adaptability and robustness to the complex processes. To demonstrate the performance of the self-tuning fuzzy PI controller (STFPIC), results are compared with a fuzzy PI controller (FPIC). It is observed that the proposed controller structure is able to quickly track the parameter variation and perform better in load disturbances and also for set point changes.

Keywords – Fuzzy controller, Self-Tuning, Pressure Control

I. INTRODUCTION

The result of automatic control must always be evaluated in terms of the quality of the finished product rather than in terms of accuracy or deviation of the controlled variable. The general purpose of automatic control is to obtain maximum efficiency of process operation. The PID controllers can successfully regulate a majority of industrial processes by meeting various specifications under consideration. However, the capabilities of the PID controllers are significantly reduced when they are applied to systems with nonlinearities such as saturation, relay, hysteresis, and dead zone. Also classical control theory requires mathematical model for the plant that allows for the design of the controller. The fact that there are fuzzy logic approaches that allow controllers to be designed without any need for a plant model, can be considered as very positive. It has been reported that fuzzy logic controllers (FLCs) are suitable for high-order and non-linear systems and even with unknown structure [1-3].

The aim of fuzzy techniques is to get ahead of the limits of conventional techniques, and to improve existing tools by optimizing the closed-loop dynamical performances. A number of approaches have been proposed to implement hybrid control structures that combine conventional controllers with fuzzy logic techniques to control the nonlinear systems [4, 5]. Among the various types of hybrid controllers, just like the widely used conventional PI controllers [6] in process control systems, PI-type FLC's are most common and practical followed by the PD-type FLC's [7, 8]. Because proportional (P) and integral (I) actions are combined in the proportional-integral (PI) controller to take advantages of the inherent stability of proportional controllers and the offset elimination ability of integral controllers.

It is well known that most industrial control systems in practice are usually non-linear and higher order systems with considerable dead time, and their parameters may be changed with changes in ambient conditions or with time. In a conventional FLC, like fuzzy PI controller (FPIC) this non-linearity is tried to be eliminated by a limited number of IF-THEN rules, but it may not produce desired control performance with fixed valued SFs and simple membership functions (MFs). In spite of a number of merits, there are many limitations while designing a fuzzy controller, since there is no standard methodology for its various design steps, and no well-defined criterion for selecting suitable values for its large number of tunable parameters. Attempts have been made to tune the control rules to achieve the desired control objectives. But, the tuning of a large number of FLC parameters can be a tough task [2]. Such problems may be eliminated by adopting self-tuning schemes [9-12]. Here, a simple self-tuning scheme is used to continuously update the controller gain with the help of fuzzy rules.

Depending on the input error (e) and change of error (Δe) of a process, an expert operator always tries to modify the output SF i.e. controller gain to enhance the system performance and to achieve stable controlled output [13]. Following such an operator's policy, here, we suggest a simple self-tuning scheme where an online fuzzy gain modifier β is determined by fuzzy rules defined on e and Δe [14-16]. Robustness of the proposed self-tuning fuzzy PI controller (STFPIC) is demonstrated to control the water pressure.

The rest of the paper is presented in the following sections. In Section II, the proposed self-tuning FLC is described in detail mentioning different aspects of its design consideration. The real time process is described briefly in section III. Experimental results are presented in section IV and conclusion is made in section V.

II. PROPOSED SELF-TUNING SCHEME OF FPIC

The simplified block diagram of the STFPIC is shown in Figure 1.

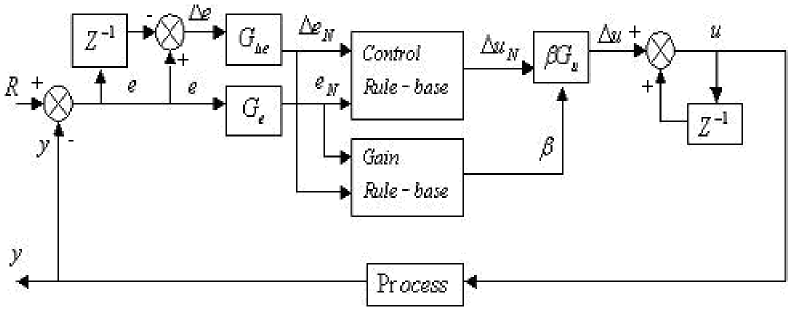

Figure 1. Block diagram of STFPIC

Membership functions for controller inputs error (e), change of error (Δe) and controller output (Δu) are defined on the normalized domain [-1, 1], whereas the MFs of β is defined on [0, 1] as shown in Figure 2 and Figure 3 respectively. Symmetric triangles with equal base width and 50% overlap with neighboring MFs are used here due to its natural and unbiased nature. The term sets of e, Δe, Δu for PI type FLC contain the same linguistic expressions for the magnitude part of the linguistic values, i.e., LE = LΔE = LΔU {NB, NM, NS, ZE, PS, PM, PB}. Similarly, MFs of β are mapped to the MFs {ZE, VS, S, SB, MB, B, VB}.

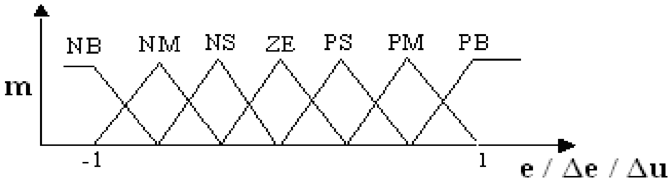

Figure 2. Membership functions of inputs (e, Δe) and output (Δu)

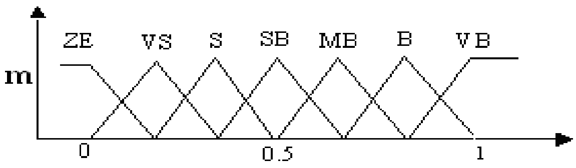

Figure 3. Membership function of gain updating factor, β

The operation of a PI-type FLC as shown in Figure 1 can be described by equation (1) u(k)=u(k-1) + Δu(k) ---------------(1)

Here, Δu is the incremental change in controller output. The rule-base for computing Δu_N is shown in Table 1. The rule-base in Table 2 is used for the computation of β. STFPIC generate the non-linear controller output (Δu) by modifying the output of simple fuzzy PI controller (FPIC) as shown in Figure 1 and equation (2).

$\Delta u = \beta G_u (\Delta u_N)$ ---------------(2), Where, G_u is the proportionality constant.

Table -1 Fuzzy rules for computation of Δu_N

Δe/e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

Table -2 Fuzzy rules for computation of β.

Δe/e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	VB	VB	VB	B	SB	S	ZE
NM	VB	VB	B	B	MB	S	VS
NS	VB	MB	B	VB	VS	S	VS
ZE	S	SB	MB	ZE	MB	SB	S
PS	VS	S	VS	VB	B	MB	VB
PM	VS	S	MB	B	B	VB	VB
PB	ZE	S	SB	B	VB	VB	VB

The proposed STFPIC uses 49 control rules and 49 gain rules as shown in Tables 1 and 2 respectively. Thus 98 rules are required to obtain the ultimate controller output u as shown in the Figure 1. Basically the rule-base for β should be developed by the designer according to the type of response one wishes to achieve. Variation of gain updating factor with inputs that is highly non-linear in nature is shown in Figure 4.

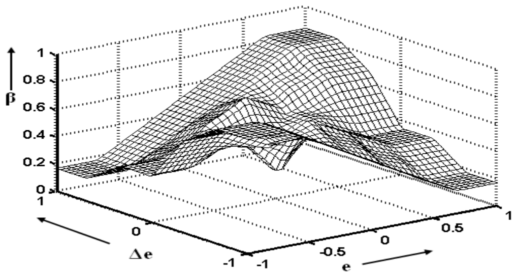

Figure 4. Variation of gain updating factor (β) with e and Δe

III. SYSTEM DESCRIPTION

The diagram of a pressure and flow control loop is shown in Figure 5. As shown in Figure 6, it consists of 1) Water reservoir 2) Pump 3) Process pipe 4) Orifice plate 5) Control valve with electro-pneumatic positioner 6) Pressure header 7) Manual Valve 8) Compressor and 9) controller etc. An open water tank is connected with inlet pipe (thorough pump), outlet pipe and with a bypass line through manual vale (MV1). System is equipped with flow transmitter, pressure transmitter and pressure gauge for measurement of process variable. Initially when controller is off condition, due to starting of constant discharge pump, control valve gets is minimum position i.e. valve is closed and thus a pressure head is created in pressure header that can be measured by pressure transmitter and pressure gauge. Now to obtain the desired pressure, we have to switch on controller. In our system we designed the controller in LABVIEW environment and PCI 6236 DAQ card is used for receiving and transmitting data. Input and output of the DAQ card is 4 to 20 ma and 0 to 10 V DC respectively. Pressure vs. control valve opening characteristic is shown in Figure 7, where we find that pressure is decreased when valve opening is increased. Pressure is measured by a pressure transmitter in the range of 4 to 20 ma. Pressure gauge reading (psi) vs. pressure transmitter reading (amp) relationship is shown in Figure 8, which is linear in nature.

Figure 5. Real time pressure loop

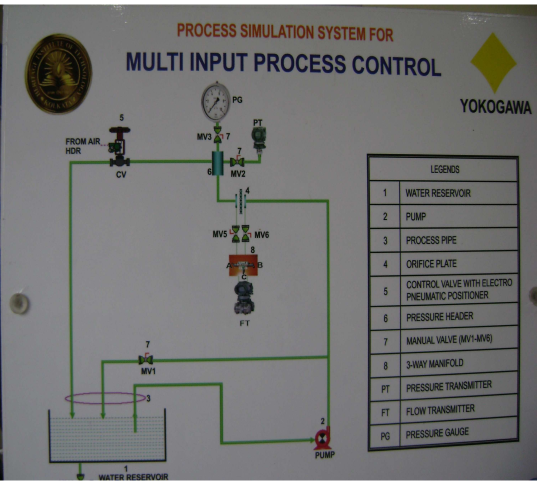

Figure 6. Schematic diagram of pressure loop

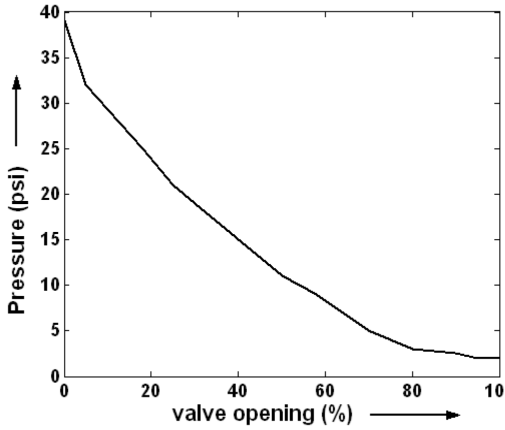

Figure 7. Control valve Characteristics

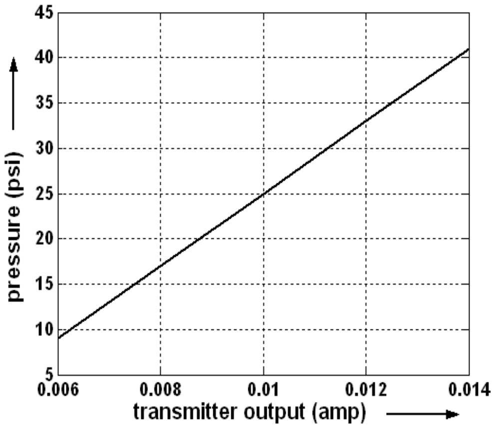

Figure 8. Pressure vs. current calibration curve

IV. RESULTS

The proposed FPIC and STFPIC are tested on a pressure control system with a constant set point 25 psi. Their performance also checked against sudden load change and set point in the process. The STFPIC outperforms the FPIC as shown in Figure 9 and Figure10. Figures show the pressure in current (amp) unit, for that calibration curve is provided in Figure 8, which is completely linear in nature. Real-time experiments on the system illustrate the advantages of proposed self-tuning scheme. From Table 3, we find that the different performance parameters such as settling time (ts), IAE, ITAE, and ISE are reduced by a large percentage when controlled by STFPIC compared to FPIC. Also the rise time of STFPIC is very less compare to FPIC. Figure 11 and 12 respectively show the error characteristics and controller output characteristics for STFPIC.

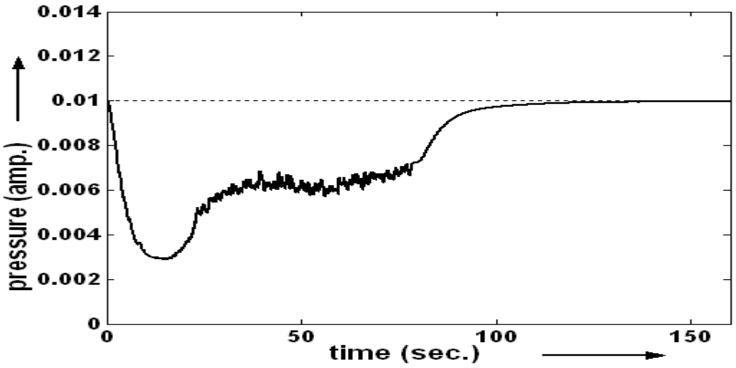

Figure 9. Process response for a set point of 25 psi (0.01amp) with FPIC

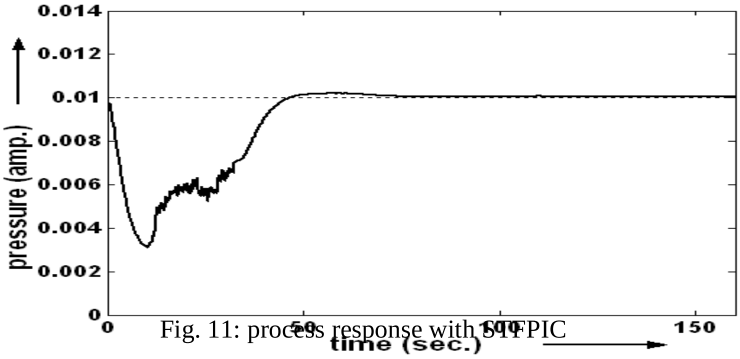

Fig. 11: process response with STFPIC

Figure 10. Process response for a set point of 25 psi (0.01amp) with STFPIC

Table -3 Performance analysis of the process

Controller	ts	IAE	ITAE	ISE
FPIC	105.8	65.1666	2639.1	0.2920
STFPIC	60.9	32.2104	715.4	0.1383

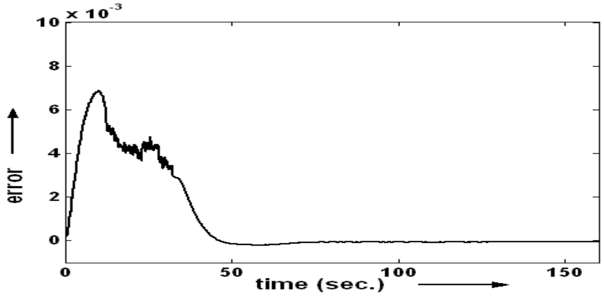

Figure 11. Error characteristics of process using STFPIC

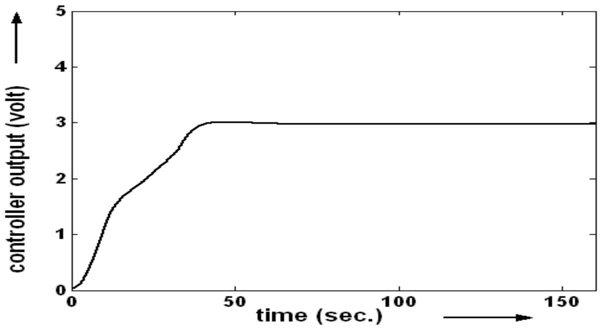

Figure 12. Output voltage of STFPIC

We also study the system with sudden load change as depicted in Figure 13 and 14 for FPIC and STFPIC respectively. Thus, the above study reveals that the proposed self-tuning scheme for fuzzy controller can fix the system in its desired pressure easily even at load change. Figure 15 shows the pressure evolution for a set point pressure change from 25 to 33 psi and again from 33 to 25 psi using STFPIC.

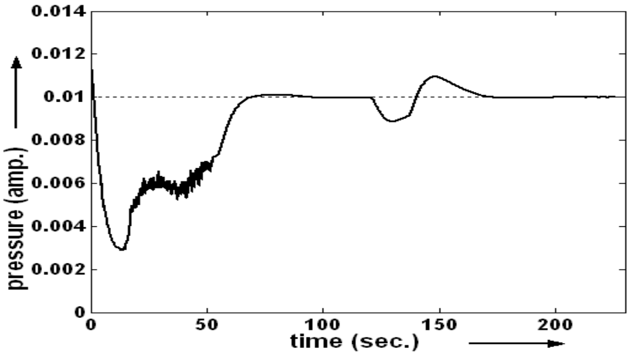

Figure 13. Pressure evolution using FPIC after load change

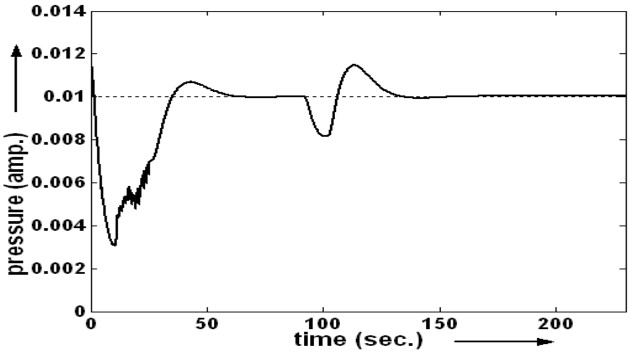

Figure 14. Pressure evolution using STFPIC after load change

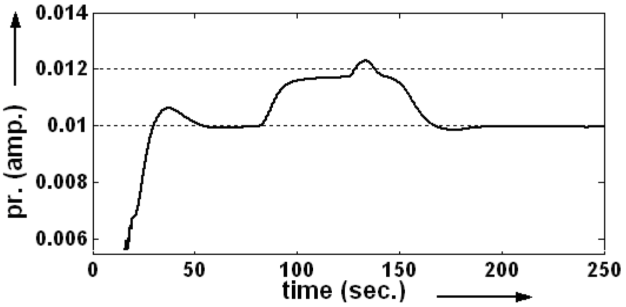

Figure 15. Pressure evolution after set point changes from 25 psi (0.01amp) to 33 psi (0.012amp) and 33 psi to 25 psi for STFPIC

V.CONCLUSION

In this paper, we proposed a simple self-tuning scheme for PI-type FLCs. Here, the controller gain (output SF) has been updated on-line through a gain modifying parameter β defined on error and change of error (Δ*e*). Our proposed STFPIC exhibited effective and improved performance compared to its conventional fuzzy counterpart. The proposed control scheme for our real time system reduces the computational complexity and is very easy to understand. By applying the proposed self-tuning method, we obtained an overall improved performance of the system even at load change and set point variations.

VI. ACKNOWLEDGEMENT

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