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Some Tuning Methods of PID Controller For Different Processes

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Abstract: *Proportional, Integral and Derivative (PID) con-trollers are the most widely used controller in the chemical process industries because of their simplicity, robustness and successful practical application. Many tuning methods have been proposed for PID controllers such as Ziegler-Nichols, Tyreus-Luyben, Cohen-Coon, IMC, IMC based PID, FuzzyPID. Our purpose in this study is comparison of these tuning methods for single input single output (SISO) systems using computer simulation. Comparative analysis of performance evaluation of different controller are performed. Such as percentage of overshoot, settling time, rise time has been used as the criterion for comparison. These tuning methods have been implemented for first, second and third order systems with dead time and for two cases of set point tracking and load rejection response has considered.*

I. INTRODUCTION

A proportional-integral-derivative controller (PID con-troller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a mea-sured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. The field of Fuzzy control has been making rapid progress in recent years. Fuzzy logic control has been widely exploited for nonlinear, high order and time delay system [2]. This paper has two main contributions. Firstly, a PID controller has been designed for higher order system using Ziegler-Nichols frequency response method and its performance has been observed. The Ziegler Nichols tuned controller parameters are fine tuned to get satisfactory closed loop performance. Secondly, for the same system a fuzzy logic controller has been proposed with simple approach and smaller number of rules (four rules) as it gives the same performance as by the larger rule set [1], [3], [7], [8], [9], [10]. Simulation results for a higher order system have been demonstrated. A performance comparison between Ziegler Nichols tuned PID controller, IMC-based PID controller,Tyreus-Luyben,Cohen-Coon PID Controller and the proposed fuzzy logic controller is presented. In this study we have compared the performances of these tuning methods. For simulation study first, second and third order systems with dead time have been employed and it was assumed that the dynamics of system is known. Simulation study has been performed for two cases of set point tracking and load rejection.The paper has been organized as follows, Section-II explains generalized model of PID controller.

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Section-III describes the design consideration for a higher order system. Section IV presents design of PID controller using Z-N technique. Section V presents design of fuzzy logic controller using simple approach and smaller rule base. Section VI finally conclusion close the paper.

II. GENERALISED MODEL OF PID CONTROLLER

The PID control logic is widely used in the process control industry. PID Controllers have traditionally chosen by the control system engineers due to their flexibility and reliability. A PID controller has proportinal, integral and derivative terms that can be represented in transfer function form as

$$K(s) = K_p + \frac{K_i}{s} + K_d s$$

where,

K_p represents the Proportional gain. K_i represents the Integral gain.
K_d represents the Derivative gain.

III. DESIGN CONSIDERATION

A PID controller is being designed for a first,second and higher order system with transfer function,

1) First order plus dead time model(FOPDT).
   $T(s) = e^{(\ 0:3s)} = (s + 1)$
   where,dead time( )=0.3 sampling time(T_s)=0.05($_1$)=1
2) second order plus dead time model(SOPDT).
   $T(s) = e^{(\ 0:3s)} = (0:4s + 1)(0:5s + 1)$
   where,dead time( )=0.3 sampling time(T_s)=0.05($_1$)=0.4 ($_2$)=0.5
3) Higher order plus dead time model.
   $T(s) = 0:0404e^{(\ 0:1s)} = s^3 + 3:27s^2 + 3:61s + 0:07107$

Fig.shows the simulink model of the PID controller and the plant with unity feedback. i) PID controller using Z-N technique (ii) fuzzy controller so that the closed loop system exhibit small overshoot Mp and settling time ts with zero steady state error ess.

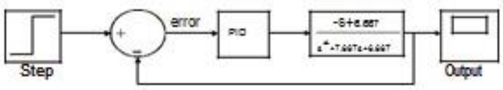

Fig. 1. A simple PID Controller system block diagram

TABLE I
ZEIGLER-NICHOLS METHOD

Controller	K_p	K_i	K_d
P	$0:5\ K_u$	–	–
PI	$0:455\ K_u$	$0:833\ P_u$	–
PD	$0:71\ K_u$	–	$0:15\ P_u$
PID	$0:6\ K_u$	$0:5\ P_u$	$0:125\ P_u$

IV. DESIGN OF PID CONTROLLER FOR DIFFERENT

TUNING METHOD

A. Ziegler-Nichols Method

Frequency response method suggested by Zeigler-Nichols is applied for design of PID controller.

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By setting T_i=1 and T_d=0 and using the proportional control action(K_p)only, the value of gain is increased from 0 to a critical value K_u at which the output first exhibits oscillations.P_u is the corresponding period of oscillation. The unit step response for different values of gain K_p were observed. The step response for the K_p=7.65 is shown in figure below: The above response clearly shows that sustained

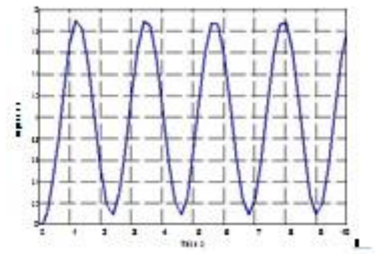

Fig. 2. Step response for K_p=7.65

oscillation occurs for K_p = K_u=7.65. The ultimate period Pu obtained from the time response is 3.14.K_u and P_u are Zeigler-Nichols parameters which can be calculated for plant by inserting the plant in setup with a step input and gain K and tuning the gain K upto which the plant output is sustained oscillations. At that time,gain K will be equal to K_u and P_u will be the time difference between two consecutive peaks.

B. Tyreus Luyben Method

The Tyreus-Luyben procedure is quite similar to the Ziegler-Nichols method but the final controller settings are different. Also this method only proposes settings for PI and PID controllers. These settings that are based on ultimate gain and period are given in below table

TABLE II
TYREUS-LUYBEN METHOD

Controller	K_p	i	d
PI	0:31 K_u	2:2 p_u	
PID	0:31 K_u	2:2 P_u	0:152 P_u

C. Cohen-Coon Method

In this method the process reaction curve is obtained first, by an open loop test as shown in Figure , and then the process dynamics is approximated by a first order plus dead time model, with following parameters:

$_m$= 3=2(t_2 t_1)

d_m= $_2$ $_m$

t_1 = time at which = 0.283 Cs t_2 = time at which = 0.632 Cs C = the plant output.

This method is proposed by Dr C. L. Smith provides a good approximation to process reaction curve by first order plus dead time model After determining of three parameters of k_m , $_m$ and d, the controller parameters can be obtained, using Cohen-Coon relations given in Table 2.3 . These relations were developed empirically to provide closed loop response with a decay ratio.

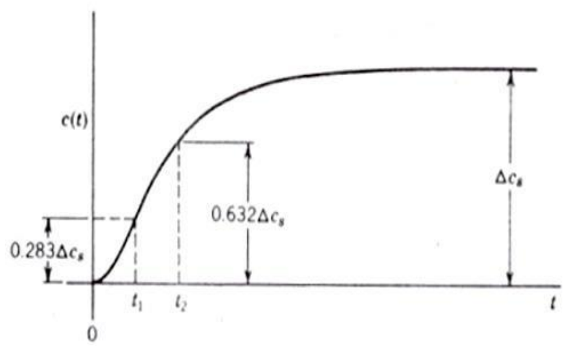

TABLE III
COHEN-COON CONTROLLER SETTING

Controller	Kp	i	d
P	1 m d / k_m d (1 + 3 m)	–	–
PI	1 m 9 d / k_m d (0 + 2 m)	d m 30+3m 9+2 / d (0 d_m)	–
PID	1 m 3 d / k m d (4 + 4 m)	d 32+6 m 13+ / d (8 d) m	4 11+ / d (2 d) m

D. Internal Model Controller

The main advantage to IMC is that it provides a transparent framework for control-system design and tuning. The IMC control structure can be formulated in the standard feedback control structure. For many processes, this standard feedback control structure will result in a PID controller (sometimes cascaded with a first-order lag). This is pleasing because we can use standard equipment and algorithms (i.e., PID controllers) to implement an “advanced” control concept.
The IMC design procedure is exactly that of the open-loop “control” design procedure. Remember that a factorization of the process model was performed so that the resulting controller would be stable. If the controller is stable and the process is stable, then the overall control system is stable.

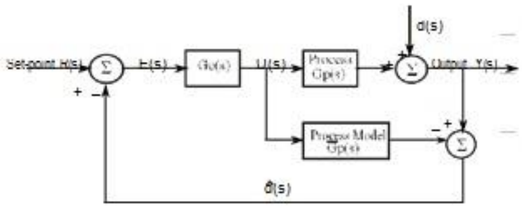

Fig. 4. Schematic of the IMC scheme

1) IMC Design Procedure: The assumption we are making is that the model is perfect, so the relationship between the output, y, and the setpoint, r, is given by equation

$y(s) = G_p(s)q(s)r(s)$. Model uncertainty is handled by adjusting the “filter factor” for robustness (tolerance of model uncertainty) and speed of response. The IMC design procedure consists of the following steps.

Develop a process model, $\hat{G}_p(s)$
Factor the process model into invertible (“good stuff”) and noninvertible (“bad stuff”-time delays and RHP zeros) portions, usually using an all-pass factorization.

$$\hat{G}_p(s) = \hat{G}_p^{+}(s)\hat{G}_p(s)$$

This factorization is performed so that the resulting controller will be stable.

Invert the invertible portion of the process model (the good stuff) and cascade with a filter that makes the controller q(s) proper.

$$q(s) = \hat{G}_p^{\ 1}(s)f(s)$$

For a focus on step setpoint changes, the following form is often used:

$$f(s) = \frac{1}{(\ s+1)^{n}}$$

and n is chosen to make the controller proper (or semiproper).

For good rejection of step input load disturbances, the form used is,

$$f(s) = \frac{s+1}{(\ s+1)^{n}}$$

where is selected to cancel the slow process time constant.

E. DESIGN OF FUZZY LOGIC CONTROLLER (FLC)

Simulink model of the fuzzy controller and the plant with unity feedback is shown in Fig For a two input fuzzy con-troller, 3,5,7,9 or 11 membership functions for each input are mostly used [7]. In this paper, only two fuzzy membership functions are used for the two inputs error e and change in error e˙ membership functions for the output parameter are shown in Fig., here N means Negative, Z means Zero and P means Positive.

TABLE IV
FUZZY RULE

e/ e	N	P
N	N	Z
P	N	P

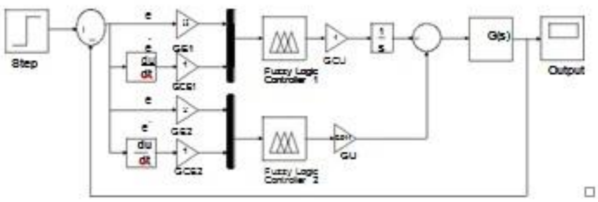

Fig. 5. System with fuzzy logic controller

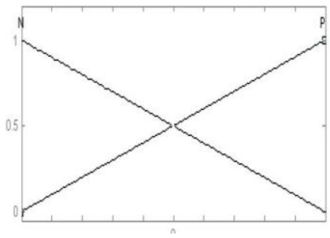

Fig. 6. Membership function for inputs e and e˙

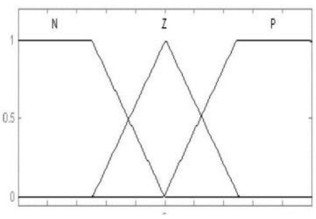

Fig. 7. Membership function for outputs

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V. RESULT AND CONCLUSION

This paper covered an overview of PID controller, design of PID controller using Z-N, T-L, C-C, IMC technique and design of fuzzy logic controller for first, second, higher order processes. Simulation results using Matlab simulink are discussed for Ziegler Nichols, Tyres Luyben, Cohen-Coon, IMC based PID controller and the Fuzzy logic controller. Ziegler Nichols technique gives high overshoot and settling time with zero steady state error. Initial controller parameters obtained using Z-N formula need to be adjusted repeatedly through computer simulation to get satisfactory performance. IMC based PID controller gives zero steady state error and smaller overshoot and settling time than Ziegler Nichols tuned PID controller but it is not applicable for higher order. The Fuzzy Logic controller gives no overshoot, zero steady state error and smaller settling time than obtained using Ziegler Nichols tuned PID controller and IMC based PID controller. The simulation results shown in table 5.1,5.2,5.3 confirms that the implemented Fuzzy logic controller with simple design approach and smaller rule base can provide better performance comparing with the Ziegler Nichols tuned PID controller, IMC based PID controller, Tyres-Luyben tuned PID controller, Cohen-Coon tuned PID controller.

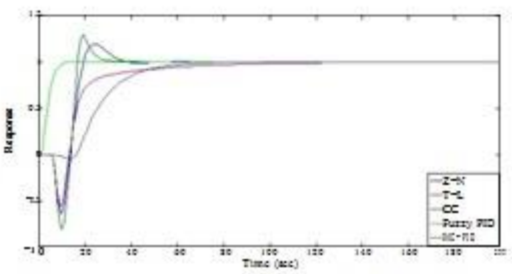

Fig. 8. Simulation plot for first order plus dead time model

TABLE V
FIRST ORDER PLUS DEAD TIME MODEL

Method	%overshoot	Ts	Tr
Z-N	18	33.32	18
C-C	28	25:48	2.32
T-L	0:0693	193.78	81:32
IMC	2:24	8:25	3:027
FUZZY PID	0:0	10:31	5:68

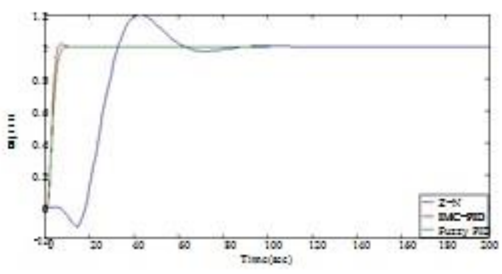

Fig. 9. Simulation plot for second order plus dead time model

TABLE VI
SECOND ORDER PLUS DEAD TIME MODEL

Method	%overshoot	Ts	Tr
Z-N	19:95	77.81	11.03
IMC	2	5:716	2:73
FUZZY PID	0:04	6:7	3:729

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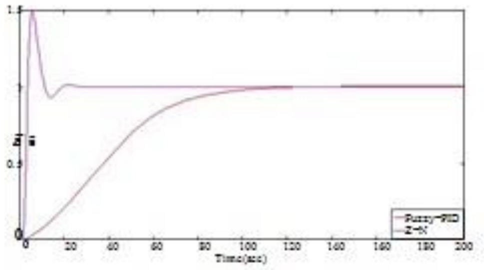

Fig. 10. Simulation plot For Higher order system

TABLE VII
HIGHER ORDER PLUS DEAD TIME MODEL

Method	%overshoot	Ts	Tr
Z-N	47:09	18.46	1.39
FUZZY PID	0	102	62

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