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DESIGN of IMC-PID CONTROLLER for a HIGHER ORDER SYSTEM and ITS COMPARISON with CONVENTIONAL PID CONTROLLER

Linkan Priyadarshini[1], J.S Lather [2]

Student, Electrical Engineering, National Institute of Technology, Kurukshetra, India [1]
Associate Professor, Electrical Engineering, National Institute of Technology,Kurukshetra, India [2]

Abstract: The proportional-integral-derivative (PID) controller is the most popular controller used in almost all process industries till date. Earlier it was first implemented in pneumatic devices but now its use is extended to analog as well as digital electronics. The presence of time delay in the system affects the stability and performance of the system. In this paper an IMC-PID controller is designed for a higher order system with time delay and is compared with the conventional PID controller. The simulation result show that the IMC controller provides better performance as compared to the conventional method.

Keywords: Generalized IMC-PID method, PID controller tuning, C-H-R method, ZN method

I. INTRODUCTION

The feedback controllers are designed by employing some form of a model for the process to be controlled and/or the dynamics of the exogenous signal affecting the process. The model-based controller design algorithm named "Internal Model Control" (IMC) has been presented by Garcia and Morari [1], which is based upon the internal model principle to combine the process model and external signal dynamics . The conventional PID controller is still widely used in chemical and process industries. The advantages of using PID controller is its simplicity, easy tuning to achieve desired time domain specifications. The tuning of PID controller refers to the determination of proportional, integral and derivative gains i.e. Kp, Ki and Kd. Many researchers [8–15] proposed PID tuning rules to control various stable systems by different methods to improve closed loop performance. A new IMC-PID tuning method based on combination algorithm of DE and NLJ is proposed [19]. Here the IMC-PID controller tuning strategy not only has the advantage of internal model control, but also includes the characteristic of conventional PID controller, but also has the advantages of internal model control.The IMC-PID tuning methods [3,7,16-17] and the direct synthesis (DS) method[6,18] are typical tuning methods based on achieving a desired closed-loop response. These methods give the PID controller parameters to obtain the desired closed-loop response. [18] proposed IMC-PID tuning method is to obtain the PI/PID setting which gives the better performance and robustness. The method requires one closed-loop step setpoint response experiment using a proportional only controller with gain k_{co}. Based on simulations for a range of first-order with delay processes, simple correlations have been derived to give PI/PID.filter controller settings. The controller gain k_{co} is only a function of the overshoot observed in the setpoint experiment. The controller integral and derivative time is mainly a function of the time to reach the first peak (tp). The proposed tuning method shows better performance than the setpoint overshoot method Time delay reduces the stability and performance of the system. It is caused due to the time taken to generate the control signals, presence of sensors in the system, transportation lag, etc. In this paper firstly a PID controller is designed for a third order system using the Chen, Hornes and Reswich (CHR) method. Secondly, an IMC-PID controller is designed for the same system and its performance is compared with the CHR method.

The entire paper is organised as follows. Section II discusses the overview of PID controller. Section III gives the designs methodology of conventional PID controller and section IV gives the design methodology of IMC-PID controller. Section V gives the technique for plant model reduction. Result and discussion is given in section VI. Finally conclusion is drawn at the end.

II. OVERVIEW OF PID CONTROLLER

The basic PID control scheme is shown in Fig 1. The error signal e(t) is the difference between the reference input r(t) and desired output y(t), i.e

$$e(t) = r(t) - y(t)$$

This error is manipulated by the PID controller to produce a command signal for the system given by-

$$U(t) = K_p[e(t) + (1/\tau_i)\int_{-\infty}^{t} edt + \tau_d(de/dt)]$$

Thus, a PID controller is described by the following transfer function in the continuous s-domain

$$G_c = P + I + D$$

$$G_c = K_P + \frac{K_i}{s} + K_d s$$

$$G_c = Kp(1 + 1/\tau_i s + \tau_d s)$$

Where-

Kp = Proportional gain
Ki = Integration coefficient
Kd = Derivative coefficient
τ_i = Integral time constant
τ_d = Derivative time constant

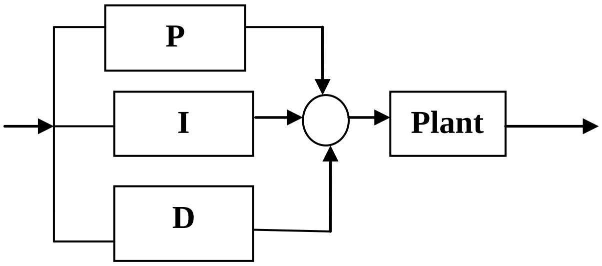


Fig. 1. Conventional PID controller

III. DESIGN OF CONVENTIONAL PID CONTROLLER

A . Design using Chien, Hrones and Reswich(CHR) method-

Tuning of conventional PID controller is done by Chien, Hrones and Reswich (C-H-R) and Ziegler Nichols (ZN) method . The C-H-R method is the modification of the open loop Zigler Nichols method. This is as shown in Table I.

B. Design using Ziegler Nichols(ZN) method.

The ZN tuning technique was the first method to tune PID controller. According to the rule, a PID controller is tuned by setting it to P controller only and increasing the value of proportional gain until the system is in a continuous oscillation. The corresponding value of proportional gain is reffered to as critical gain(k_c) and the oscillation period as critical time period(T_c). then the PID parameters are determined according to Table. II.

TABLE I: C-H-R method

Controller	K_C	τ_I	τ_D
P	$\frac{0.7\tau_m}{K_m\tau_d}$	---	---
PI	$\frac{0.6\tau_m}{K_m d}$	τ_m	---
PID	$\frac{0.95\tau_m}{K_m d}$	$1.4\tau_m$	$0.47d$

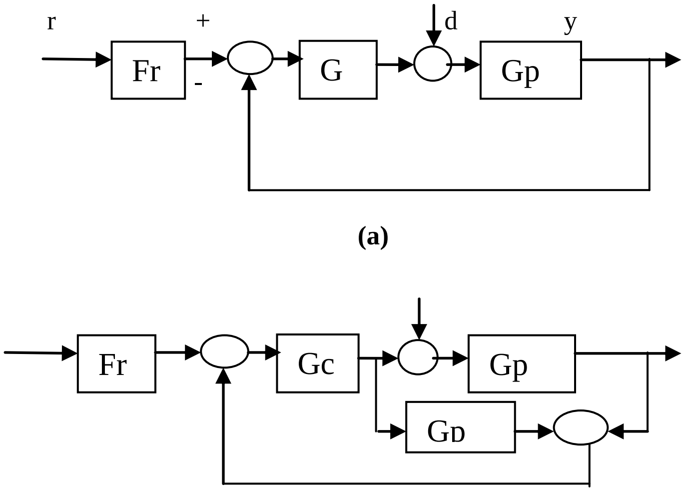
TABLE II: ZN method

Controller	K_c	τ_i	τ_d
P	$0.5k_c$	-----	-----
PI	$0.45k_c$	$0.833T_c$	-----
PID	$0.6k_c$	$0.5T_c$	$0.125T_c$

IV. PROPOSED SCHEME OF PID TUNING

Proposed scheme used in this paper is tuning of controller parameters using internal model control. the control block diagram is as shown in fig.2. Here G_P is the process transfer function, is the controller transfer function, q is the imc controller and F_r is the set point filter.
Let us consider a first order with dead time(fopdt) given by-

$$G_P = \frac{K_m e^{-ds}}{\tau_m s + 1} \qquad \textbf{(1)}$$



(a)

(b)

Fig. 2. (a) classical feedback (b) internal model controller

Here the disturbance is assumed to be zero.
The output y of the conventional feedback controller is given by-

$$y = \frac{G_C G_P}{1 + G_C G_P} r \qquad (2)$$

The output of the IMC controller for set point change is given by-

$$y = \frac{q G_P}{1 + q(G_P - \widetilde{G}_P)} r \qquad (3)$$

Comparing eqn.(2) and (3) we get the conventional feedback controller in terms of IMC controller given by-

$$G_C = \frac{q}{1 - \widetilde{G}_P q} \qquad (4)$$

The steps for designing the IMC-PID controller are as follows-

1. The process model G_P of eqn (1) is factorised into two parts given by-

$$G_P = P_m P_A \qquad (5)$$

where, P_m is the non- inverted part of the process model G_P and P_A is the inverted part of the process model that contains the delay part and the right-half zeros.

2. The controller is then specified as-

$$q = \frac{1}{P_m} f \qquad (6)$$

$$q = P_m^{-1} f \qquad (7)$$

Where, the IMC filter is given by-

$$f = \frac{1}{(\lambda s + 1)^n} \qquad (8)$$

where n is selected in such a way that the IMC controller becomes proper.

3. Then convert the conventional controller to IMC controller using eqn (4).

V. PLANT MODEL REDUCTION

As it is difficult to implement IMC controller directly to higher order system due to increased complexity, so it is reduced to a low order model. The method used to reduce the model in this paper is given by the half rule. According to this rule the largest neglected (denominator) time constant (lag) is distributed evenly to the effective delay and the smallest retained time constant.

Let the original model be given by

$$\frac{\prod_{I=1}^{m}(-T_{j0}^{inv}+1)}{\prod_{j=1}^{n}\tau_{i0}s+1} e^{-\theta_0 s} \qquad (9)$$

Then according to Half-rule to obtain a first-order model of the form given by eqn (2) we have-

$$\tau_I = \tau_{10} + \frac{\tau_{20}}{2} \qquad (10)$$

$$\theta = \theta_0 + \frac{\tau_{20}}{2} + \sum_{i \geq 3} \tau_{i0} \sum_j T_{j0}^{inv}$$

VI. MATHEMATICAL MODEL OF THE PLANT

The plant/process with time delay considered is

$$G_P(s) = \frac{2e^{-s}}{(2s+1)(s+1)^2} \qquad (11)$$

Reducing this model using the half rule we get

$$G_P(s) = \frac{2e^{-1.5s}}{2.5s+1} \qquad (12)$$

VII. SIMULATION AND DISCUSSION

The simulations are carried out in MATLAB/SIMULINK. Analysis shows that the design of the controller using proposed method gives better results than the conventional controllers. The performance and robustness of the time delay system was evaluated in terms of time domain specifications and performance indices IAE & ISE. PID controller parameters for the tuning methods are shown in table III. A reference step input is given to the system with time delay.

The response curve of the ZN method (Fig. 3) gives an unstable oscillating effect with very higher overshoot (M_p) and large settling time (t_s). The calculated performance indices IAE and ISE are also very large.

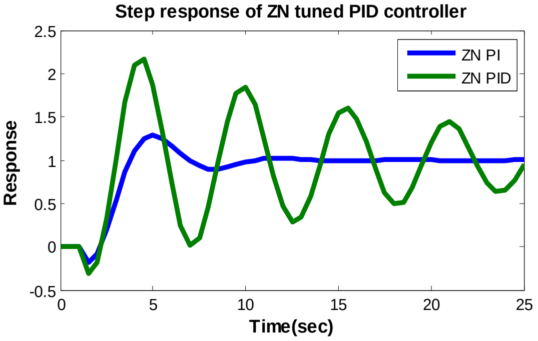


Fig. 3. Step response of system using ZN method

From Step response of system using CHR method (Fig.4), it is observed that CHR method gives better performance in comparison to ZN method.

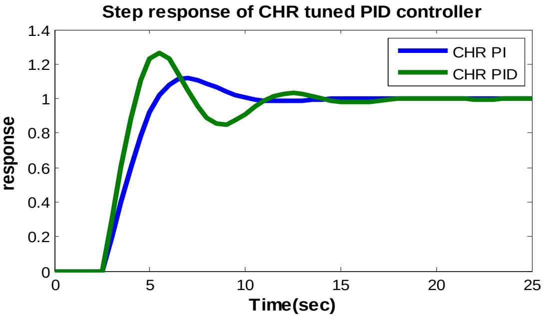


Fig. 4. Step response of system using CHR method

Tuning of the controller using IMC method gives the best result. This can be seen from Fig. 5. The calculated Performance index (IAE and ISE) is also reduced to a great extent.

Based on the responses the time domain specifications and performance indices by ZN, CHR and IMC tuning method are tabulated in Table IV and V respectively. Comparison of time domain specifications such as overshoot and settling time show the effectiveness of the proposed scheme.

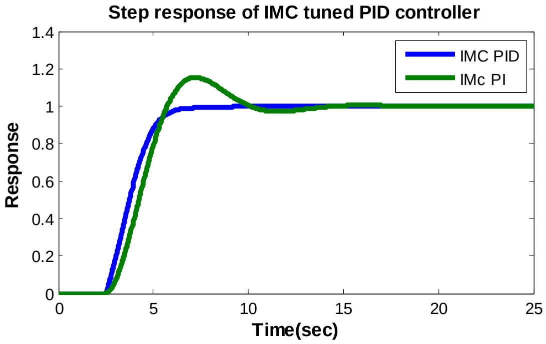


Fig. 5. Step response of system using IMC method

Tuning Method	K_c	τ_i	τ_d
ZN PI	*0.866*	*2.980*	*----*
ZN PID	*1.30*	*1.86*	*0.44*
CHR PI	*0.5*	*0.2*	*---*
CHR PID	*0.791*	*0.226*	*0.558*
IMC PI	*0.568*	*0.227*	*---*
IMC PID	*0.684*	*0.227*	*0.291*

Table. III. PI/PID controller parameter

Table. IV. Comparison of Time domain specifications

	ZN PI	ZN PID	CHR PI	CHR PID	IMC PI	IMC PID
PO (%)	28.8	118	0	0	0	0
Settling time (sec)	10.1	67.2	9.78	12.2	9.45	10.9

The robustness of the proposed scheme is analysed by calculating its performance indices as tabulated in Table V.

Table. V. Comparison of Performance Indices

	ZN PI	ZN PID	CHR PI	CHR PID	IMC PI	IMC PID
IAE	3.939	11.88	3.167	3.316	1.802	2.202
ISE	2.429	8.422	2.372	2.196	3.028	1.365

VII. CONCLUSION

This paper represents the designing and performance evaluation of conventional and IMC controller for a higher order plant. The various results presented above show that IMC is a better technique of PID tuning than conventional tuning methods. Simulation results for the process show the effectiveness of the proposed scheme. From the time domain specifications it has been proved that IMC based system produce less overshoot and reduce the settling time. The performance indices IAE and ISE (table V) under the entire error criterion are observed to be better for the proposed controller.

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BIOGRAPHY

Linkan Priyadarsini received her Bachelor of Engineering degree from the department Instrumentation and Control Engineering from NM Institute of Engineering and Technology. affiliated to Biju Pattnaik University of Technology(BPUT). Orissa, India in 2010. Currently she is pursuing Master Degree in Control System,National Institute of Technology,Kurukshetra, Haryana. Her areas of interests include PID controller, Control systems and Time Delay.

J S Lather did his Ph.D in Electrical Engineering. His research interests are Robust Control, Flexible AC Transmission systems, Mining Techniques and Decision Trees, ANN and Fuzzy Logic. He is currently working as an Associate Professor in the Electrical Engineering Department at National Institute of Technology, Kurukshetra, Haryana , India.