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Design Of FOPDT PID Controller By Different Tuning Methods For Industrial Process Control

Poorvi Jain[1]and Pramod Kumar Jain[2]
[1].M.Tech Scholar, Electronics & Instrumentation Engineering Department, Shri G.S.I.T.S, Indore, India
[2]. Associate Professor, Electronics & Instrumentation Engineering Department, Shri G.S.I.T.S, Indore, India

Abstract
PID controllers have become the most predominant control element for industrial process control . Programs used for industrial process control are written in many software tools but this paper focuses on MATLAB simulation . In this paper, an optimal method for tuning PID controllers for first order plus time delay systems is presented using dimensional analysis and numerical optimization techniques,. PID tuning formulas are derived for first order plus delay time (FOPDT) processes based on IMC principle and comparing it with the tuning methods proposed by Ziegler-Nichols' and Cohen Coon . To achieve smooth output response, examples from previous works are included for comparison, and results confirm the improvement in the output response. Simulation results show that the proposed method has a considerable superiority over conventional techniques.
Keywords: Cohen - Coon method, FOPDT process, IMC method , Ziegler-Nichols method

I. Introduction

A particle board plant is baggase based Agro industry manufacturing which uses a relay contractor logic that operates on different sections of plant. The relay contractor affects the efficiency and speed of the plant.In order to increase the efficiency and speed of the plant , an efficient controller with feedback is to be employed. It is generally believed that PID controllers (as a stand alone controller, as part of hierarchical, distributed control systems, or built into embedded components) with their remarkable effectiveness and simplicity of implementation, these controllers are overwhelmingly used in industrial applications[1], in large factory, also in robotics, polymarisation furnaces, instruments and laboratory equipment, and more than 90% of existing control loops involve PID controllers[2]. Since the 1940s, many methods have been proposed for tuning these controllers, but every method has brought about some disadvantages or limitations[1].

In this paper we discuss the basic ideas of PID control and the methods for choosing the parameters of the controllers.

The ideal version of the transfer function of the PID controller is given by the formula

$$G_{PID}(s)= K_c\left[1+\frac{1}{T_i s}+sT_d\right] \quad (1)$$

where K_c is the proportional gain , T_i is the integral time constant and T_d the derivative time costant. The aim of PID control design is to determine PID parameters(K_c , T_i and T_d) to meet a given set of closed loop system performance requirements.

II. First Order Plus Time Delay Models

To control the industrial process as stated in above example of Particle Board Plant or any industrial plants can approximately be modeled by a first order plus time delay (FOPTD) process.

Let the transfer function as follows:

$$G_M(s) = \frac{K e^{-\theta s}}{(\tau s+1)} \quad (2)$$

Various methods have been used to design PID controllers such as Ziegler- Nichols and Cohen-Coon methods but internal model control (IMC) structure has also become the most prominent techniques in developing effective control strategies for FOPDT processes.

III. Conventional techniques

3.1 Ziegler-Nichols and Cohen-Coon Method

As concluded from the previous researches [3] , the derived formulas or the design equations of PID controller in case of Ziegler and Nichols and Cohen and Coon tuning methods is analyzed. For a given FOPDT process the PID controller design parameters K_c , T_i and T_d for the above two methods are calculated as stated in the Table 1.The controller is connected to the process and by making proper adjustment of the controller parameters the system starts to oscillate. The step response is measured by applying a step input to the process and recording the response.

One of the limitation of the Ziegler-Nichols and Cohen - Coon methods is that the resulting closed loop system is often more oscillatory than the desired signal.

IV. Proposed Method (Internal Model Control)

This paper proposes an IMC structure and to propose a set of formulas for tuning a PID controller for an FOPTD model.IMC scheme provides time delay compensation [5].

In open loop control strategy, controller $G_C(s)$, is used to control the process $G_P(s)$, and $G_M(s)$ is the model of $G_P(s)$.To achieve perfect control without feedback following condition must be satisfied :

(i) $G_C(s) = G_M(s) - 1$ (ii) $G_P = G_M$ (3)

4.1 IMC Structure

In feedback implementation , process-model mismatch is common and the above two condition is not satisfied. The IMC structure as shown in Figure (1) consists of d(s) is an unknown disturbance affecting the system. The manipulated input U(s) is introduced to both the process and its model. The process output, Y(s), is compared with the output of the model, resulting in a signal K(s). That is, $U(s)$

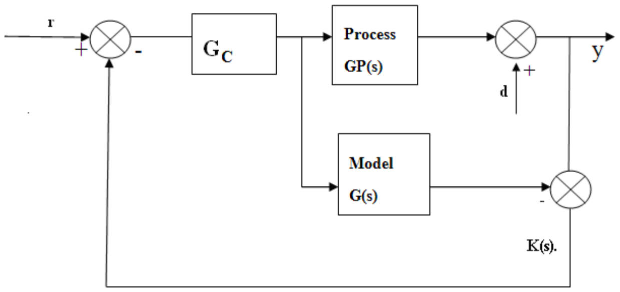

Fig. 1. IMC block diagram

$$K(s) = [G_P(s) - G_M(s)]\, U(s) + d(s) \quad (4)$$

If $d(s)$ is zero for example, then $K(s)$ is a measure of the difference in behavior between the process and its model. If $G_P = G_M$, then $K(s)$ is equal to the unknown disturbance. Thus $K(s)$ may be regarded as the information that is missing in the model, $G_M(s)$, and can therefore be used to improve control. This is done by subtracting $K(s)$ from the set-point $R(s)$, which is very similar to affecting a set-point trim. The resulting control signal is given by,

Thus,

$$U(s) = \frac{[R(s)-d(s)]G_c(s)}{1+\left[G_p(s)-\tilde{G}_p(s)\right]G_c(s)} \quad (5)$$

Since $Y(s) = G_P(s)\, U(s) + d(s)$ (6)

The closed loop transfer function for the IMC scheme is therefore

$$Y(s) = \frac{G_C(s)G_P(s)R(s)+[1-G_C(s)G_M(s)]d(s)}{1+[G_P(s)-G_M(s)]G_C} \quad (7)$$

if equation (3) condition is satisfied, then perfect set-point tracking and disturbance rejection is achieved.

Even if $G_P(s) \neq G_M(s)$, perfect disturbance rejection can still be realized provided (i) condition of eq. (3) satisfies . $Y(s) =$

$$\frac{G_{IMC}(s)G_P(s)R(s)+[1-G_{IMC}G_M(s)]d(s)}{1+[G_P(s)-G_M(s)]G_{IMC}(s)} \quad (8)$$

4.2 IMC Controller Design

First part of IMC controller design is to factor the process model $G_M(s)$ into invertible $G_I(s)$ and non-invertible component $G_{NI}(s)$, $G_M(s) = G_I(s)\, G_{NI}(s)$ then:

$G_{NI}(s) = e^{-\theta s}$ $G_I(s) = \frac{K}{(\tau s+1)}$ (9)

The non invertible component, $G_{NI}(s)$, contain term which if inverted,will lead instability and reliability problem, e.g. term containing positive zeros and time delays. Next, set $G_C(s) = G_I(s)$ and then $G_{IMC}(s) = G_C(s)\, G_f(s)$ where $G_f(s)$ is a low pass function of appropriate order is used to attenuate the effects of process-model mismatch. τ_f is the filter parameter and range is $\theta < \tau_f < 1.5\,\theta$.

4.3 PID Controller Design

The transfer function of PID controller $G_{PID}(s)$ implemented with the IMC scheme is given by

$$G_{PID}(s) = \frac{G_{IMC}(s)}{1-G_{IMC}(s).G_M(s)} = \frac{G_I(s).G_f(s)}{1-G_{NI}(s).G_f(s)} \quad (10)$$

The dead time $e^{-\theta s}$ is approximated by pade expansion as

$$exp(-\theta s) \approx \frac{1-\frac{\theta}{2}s}{1+\frac{\theta}{2}s}$$

$$G_M(s) = \frac{K exp(-\theta s)}{1+\tau_s} \approx \left(\frac{K}{1+\tau_s}\right)\frac{\left(1-\frac{\theta}{2}s\right)}{1+\frac{\theta}{2}s}$$

$$G_I(s) = \frac{K}{(1+\tau_s)\left(1+\frac{\theta}{2}s\right)} \text{ and } G_{NI}(s) = 1-\frac{\theta}{2}s$$

Simplifying, we obtain

$$G_{PID}(s) = \frac{(1+\tau)\left(1+\frac{\theta}{2}s\right)}{K\left(\tau_f+\frac{\theta}{2}\right)s} \quad (11)$$

Again, by comparing this against the ideal PID controller of eq. (1) we get

$$K_c = \frac{(\tau+\theta/2)}{K(\tau_f+\theta/2)} \qquad T_i = \frac{\theta}{2}+\tau \qquad T_d = \frac{\tau\theta}{2\left(\frac{\theta}{2}+\tau\right)}$$

PID Controller parameters of all the stated mehods are given in Table-1.

Table 1. PID Controller parameters for the Ziegler-Nichols, Cohen - Coon and IMC method for first order plus time delay system

FOPTD Model	PID parameters	Zeigler – Nichols parameters	Cohen-Coon parameters	IMC parameters
$G_{PID}(s)$	K_c	1.785	2.347	1.09523
	T_i	0.541	0.658	1.15
	T_d	0.135	0.103	0.1304

V. Simulation Verification

One example is presented in this section to illustrate the methodology discussed in the preceding section. Also, the method proposed by Ziegler-Nichols' and Cohen - Coon has been considered here for comparison study. Consider the process given in

$$G_M(s) = \frac{2\,e^{-0.3s}}{(s+1)}$$

The proposed PID with low pass filter gives Kc = 1.09523, Ti = 1.15, Td = 0.1304, τf=1.095 . Figure 2, 3 and Figure 4 shows the unit step output response in MATLAB simulation without and with PID controller where overshoot problem is solved by set-point filter and proper values of PID parameters .

VI. Conclusion

A modified IMC structure has been proposed for FOPDT process. The method ensures a smooth and noise free process output.. A PID controller designed in terms of process model parameter and low pass filter time constant from the IMC structure. The controllers perform well for set-point tracking. The simulation results also concluded that Cohen Coon method has an overshoot of more than 100%, while Ziegler Nichols method shows some improvement in its response but the proposed method have much faster response time and gives satisfactory and improved result as compared to some previous work on PID control and is useful in the industrial process control application.

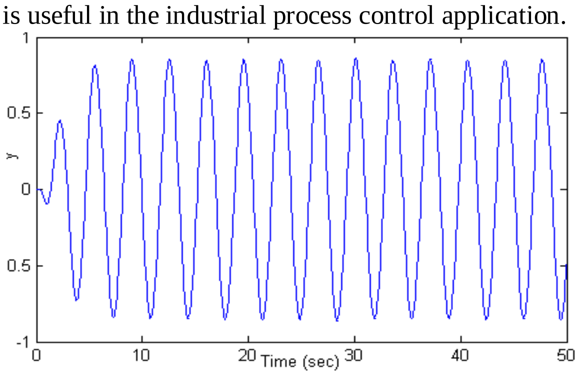

Fig 2. Unit step response without PID Controller

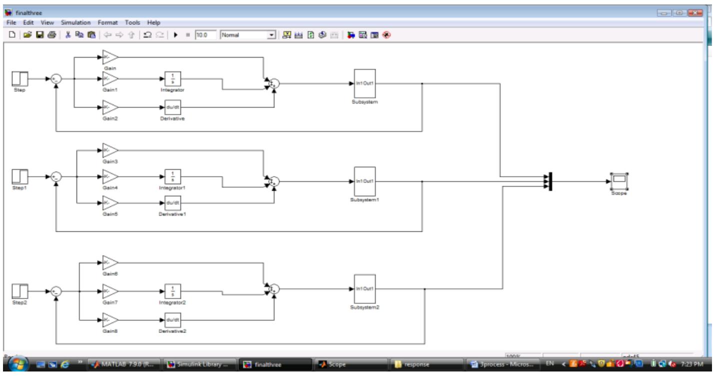

Fig 3. PID CONTROLLER(Ziegler-Nichols method, Cohen-Coon method, IMC method)

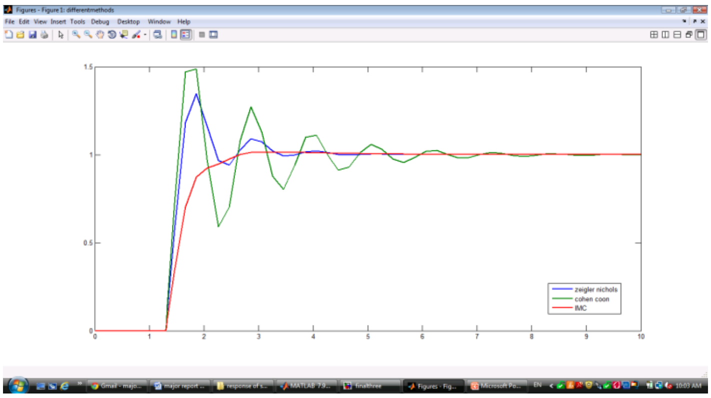

Fig 4. Unit Step Response of PID CONTROLLER (Zeigler - Nichols method, Cohen-Coon method, MC method

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