www.icgst.com

Simple Tuning Rules of PID Controllers for Integrator/Dead time Processes

A. Alenany, O. Abdelrahman, I. Ziedan
Department of Computers and Systems, Faculty of Engineering, Zagazig University,
Zagazig, Egypt
alenany102@hotmail.com
othmanalkhatib@hotmail.com
iziedan@yahoo.com

Abstract

In this paper, simple rules for tuning PID controllers for integrator/dead time processes are proposed. These rules are derived by the optimization of a discrete-time error integral criterion called the *switch time weighted summation of squared error* (SWSSE) criterion. In this criterion, the first *M* samples of the transient response are weighted by 1, while the remaining samples until the end of the response are heavily weighted by e.g. 10^4. The instant, *M*, of applying the large weight affects the characteristics of the response.

By choosing *M* that achieves the minimum possible settling time, it is found that the optimal controller for servo problem is PD, while for regulatory problem it is PID. To get a single set of rules, a two-degree of freedom (2DOF) controller is then proposed, in which the PID settings for load disturbance rejection is used in addition to a first-order set-point filter to improve the set-point response.

The proposed rules achieve good settling time, nearly no overshoot, fast load disturbance rejection and fair control effort. The robustness of the proposed method is quite acceptable.

Keywords: *PID control, Error criteria, Integrator/dead time Processes, Optimization.*

1. Introduction

Integrating processes with dead time frequently encountered in the process industries are most commonly associated with level control problems [5]. Recently, the control of integrating processes with dead time has become very active because it is a special case of unstable processes with dead time [6].

The conventional PID controller can be used for this type of processes [7]. PID controllers are still the most commonly used controller, but a main problem with PID controllers is that they are not always used in the best way [1].

There are many design methods for the PID controllers found in the literature [7]. For example, the Ziegler-Nichols rules aim to impose a decay ratio of 0.25 to the set-point step response. But this is found to be too oscillatory and tend to have large overshoot [10]. Chien and Fruehauf [9] proposed tuning rules derived from the Internal Model Control (IMC) structure which is a direct synthesis method for controller design. It was pointed out [10] that the closed-loop time constant in the method of Chien and Fruehauf should be carefully specified or the control will be poor and very oscillatory. To solve the problem, Tyreus and Luyben [10] proposed a PI tuning rule in order to obtain a maximum closed-loop log modulus = 2dB. Zhang and Sun [11] pointed out that the response of Tyreus and Luyben method is so sluggish that it cannot be applied. Poulin and Pomerleau [8] designed PI and PID controllers for integrating and unstable processes to obtain the minimum integral of time multiplied by the absolute error (ITAE) for a step load disturbance. The resultant closed-loop transfer function has a zero which produces large overshoot. For set-point changes, the problem can be easily resolved, without changing the closed-loop properties, by canceling the zero with a first-order set-point filter with a time constant equal to the controller integral time [8]. Wang and Cluett [5] use the desired control signal trajectory as a performance specification to solve for the PID controller parameters in the frequency domain. Via a simulation example in [4], it was shown that the method of Wang and Cluett gives too sluggish set-point response and load disturbance rejection. Using a genetic algorithm, Visioli [4] proposed tuning rules of PID controller for integrator/dead time process to minimize the ISE, ITSE and ISTE criteria. Visioli proposed separate rules for set-point tracking and load disturbance rejection. The optimal controller for servo problem is found to be a PD controller, which gives offset for regulatory problems [12]. In this work, also, a PID controller is tuned in order to optimize an error integral criterion.

The paper is organized as follows: The problem is specified in section 2. The SWSSE criterion is presented in section 3. The proposed tuning rules are presented in section 4. The robustness of the proposed rules is compared to a number of the other rules proposed in the literature in section 5. Simulation examples are shown in section 6. Concluding remarks are presented in section 7.

2. Problem formulation

A simple feedback control system is shown in Figure 1 and is consisted of process $G_p(s)$ and a controller $G_C(s)$.

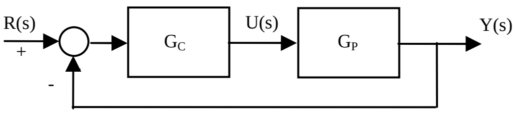

Figure 1. Feedback control system

In this paper, the process $G_P(s)$ is modeled by an integrator and dead time as:

$$G_P(s) = \frac{K}{s} e^{-Ls} \quad (1)$$

Where K is the process gain and L is the process dead time.

The controller $G_C(s)$ is a PID controller of the following form which is called the parallel form

$$G_C(s) = K_p + \frac{K_i}{s} + K_d s \quad (2)$$

Where K_P is the proportional gain, K_i is the integral gain and K_d is the derivative gain. The previous form can be transformed to the ideal form given by

$$G_C(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s\right) \quad (3)$$

Where T_i is the integral time and T_d is the derivative time.

The zero-order hold (ZOH) equivalent of the process given by Equation (1) is

$$G(z) = \frac{KT}{z-1} z^{-m} \quad (4)$$

Where T is the sampling period and $m=L/T$ is the number of delay units.

The discrete approximation of the PID controller given by Equation (2) is [2]:

$$G_c(z) = \frac{q_1 z^2 + q_2 z + q_3}{z(z-1)} \quad (5)$$

Where q_1, q_2, and q_3 are the coefficients of the discrete controller. They are related to the continuous controller parameters by the following relations [2]:

$$\begin{aligned} q_1 &= (K_P + K_i T + K_d / T) \\ q_2 &= (-K_p - 2K_d / T) \\ q_3 &= K_d / T \end{aligned} \quad (6)$$

Re-arranging gives the continuous controller gains

$$\begin{aligned} K_P &= -q_2 - 2q_3 \\ K_i &= (q_1 + q_2 + q_3)/T \\ K_d &= q_3 T \end{aligned} \quad (7)$$

The aim of this paper is to find tuning rules for selecting the PID controller parameters for the processes modeled by Equation (1).

3. The SWSSE criterion

An intuitive and commonly used measure of system performance is the integral of time weighted squared error given by:

$$J_n = \int_0^\infty t^n e(t)^2 \, dt \quad (8)$$

Where $e(t)$ is the error. Or, in discrete form:

$$J_n = \sum_{k=0}^{\infty} k^n e^2(k) \quad (9)$$

Where $e(k)$, k = 0, 1, 2… is the error at the kth sampling instant.

Also, the absolute error can also be used. But the squared error criteria can be evaluated in the s-domain using Parseval's formula [3].

Putting n = 0 in Equation (8) corresponds to the integral of squared error (ISE) criterion. The ISE criterion gives a step response with large overshoot and large settling time [4]. So, time weighting is applied to put much penalty on the late errors in the response to oblige the response to settle faster.

Also, the following criterion, was proposed by Dan-Isa and Atherton [2]

$$J_s = \sum_{k=0}^{N} w_s(k) e^2(k) \quad (10)$$

Where N is a large fixed number, e.g. 100 and the weighting function is $w_s(k)$ and is given by:

$$w_s(k) = \begin{cases} 1 & k < M \\ W & k \geq M \end{cases} \quad (11)$$

This criterion has an intuitive physical meaning. It weights the first M errors by 1 and the late errors are heavily weighted by a very large weight W e.g. 10^4. Thus late errors are not allowed because it will contribute a large penalty to the overall value of the criterion. Since the constant weight W is applied from a particular time MT, Dan-Isa and Atherton [2] called the criterion J_s the *switch time weighted summation of squared error criterion*. So, in this paper it will be referred to as the SWSSE criterion.

In order to use the SWSSE criterion, Dan-Isa and Atherton [2] gave general guiding notes for selecting the sampling period T and the switching instant M. also, they showed via two examples how this criterion can be used in optimizing the closed-loop response. But, they did not devise tuning rules for the PID controller based on this criterion. Thus, this paper tries to exploit the SWSSE criterion to devise tuning rules for PID controller for a special type of models, i.e., the integrator/dead time process given by Equation (1).

As shown in [2], the selection of a suitable value for M needs some care as it has a big effect on the response characteristics like: the rise time, Overshoot, settling time and the initial control output. This will be illustrated by the following example.

Example 1: Effect of the switching instant *M*

For the following process: