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PID controller tuning for desired closed-loop responses for SISO systems using impulse response

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Abstract

Most of the proportional-integral-derivative (PID) controller tuning methods reported in literature are based on the approximate plant models (FOPDT or SOPDT models) derived from the step response of the plant. In this paper, a new method of designing PID controllers using 'impulse response' instead of 'step response' of the plant is presented. Treating the impulse response of the plant as a statistical distribution, the 'mean' and the 'variance' of the distribution are calculated and used in the calculation of PID controller parameters. Thus, the proposed method requires no approximation of the plant by any model. In this paper, a direct synthesis approach to PID controller design is proposed that makes use of Maclaurin series of the desired closed-loop transfer function, truncated up to the first three terms. PID controller parameters are synthesized to match the closed-loop response of the plant to the desired closed-loop response. Formulae for the calculation of PID controller tuning parameters are derived for the desired closed-loop response models of the types FOPDT and SOPDT. Only stable SISO systems are considered. The PID controllers tuned result in closed-loop responses very close to the desired response and perform equally well compared to other tuning methods reported in literature.

Keywords: PID controller; Impulse response; Controller tuning; Method of moments

1. Introduction

Proportional-integral-derivative (PID) controllers have been widely used in process industries for decades. The major reasons for their wide acceptance in industries are their ability to control most of the processes, well-understood control action and ease of implementation. Design and tuning of PID controllers has been the subject of many researchers working in this field. Many researchers have provided PID controller settings for various process models and different performance criteria.

Ziegler and Nichols (1942) provided a classical method for designing PID controllers which is still used as a preliminary design by many. The other alternative to preliminary design of PID controllers was the settings given by Cohen and Coon (1953). These well known tuning relations were developed to provide closed-loop responses with one-quarter-decay ratio as the performance criteria. Smith and Corripio (1985) developed a synthesis method to design PID controllers. Lopez, Murrill, and Smith (1967) provided the PID tuning relations for minimum error integral performance criteria. The direct synthesis method by Smith, Corripio, and Martin (1975) and the internal model control (IMC)–PID tuning methods by Rivera, Morari, and Skogestad (1986) and Morari and Zafiriou (1989) are based on achieving a desired closed-loop response. Lee, Park, Lee, and Brosilow (1998) derived equations for determining the PID controller parameters for general process models by approximating the feedback form of an IMC controller with a Maclaurin series. Skogestad (2003) presented some analytical rules for PID controller tuning based on the IMC–PID tuning rules. Recently, Padma Sree, Srinivas, and Chidambaram (2004) presented a simple method of PID controller tuning for stable and

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unstable first-order-plus-dead-time (FOPDT) processes. Their method is based on matching the coefficients of corresponding powers of s in the numerator and the denominator of the closed-loop transfer function of a servo problem.

All the tuning relations reported in literature are based on the approximate plant models derived from the step response of the plant. In this present work, a new method for designing PID controllers using the impulse response is proposed. Treating the impulse response of a plant as a statistical distribution, the mean and variance of the distribution are calculated and used in the calculation of PID controller parameters. Thus, the proposed method requires no approximation of the plant by any model such as a first-order-plus-dead time (FOPDT) or second-order-plus-dead time (SOPDT) model. A direct synthesis method of PID controller design is proposed that uses the first three terms of the Maclaurin series of the desired closed-loop transfer function. The PID controller parameters are synthesized to match the closed-loop response of the plant with the controller to the specified desired closed-loop response. Only stable processes are considered. The derivation of PID controller tuning relations for the desired closed-loop response models of the types FOPDT and SOPDT is presented in Section 2. In order to test the appropriateness or suitability of the proposed approach of PID controller design, the bench mark problems reported in Lee et al. (1998) and Skogestad (2003) and the corresponding closed-loop transfer function parameters were chosen for comparative study. Simulation results and the comparison of the proposed method with other methods are presented in Section 3.

2. Development of PID controller tuning relationships

Consider the block diagram of the feedback control system shown in Fig. 1.

The objective is to design a PID controller, $G_c(s)$ of Fig. 1, that will give the desired closed-loop response, Y/R, as specified by $G_d(s)$ which is described either by FOPDT or SOPDT model. The actual closed-loop response of the control system in Fig. 1 is denoted as $G_A(s)$ and is given by

$$G_A(s) = \frac{Y(s)}{R(s)} = \frac{G_c(s)G_p(s)}{1 + G_c(s)G_p(s)} \tag{1}$$

Both $G_A(s)$ and $G_d(s)$ can be represented by Maclaurin series expansion in s at $s = 0$ as

$$G_A(s) = G_A(0) + sG'_A(0) + \frac{s^2}{2!}G''_A(0) + \frac{s^3}{3!}G'''_A(0) + \cdots \tag{2}$$

$$G_d(s) = G_d(0) + sG'_d(0) + \frac{s^2}{2!}G''_d(0) + \frac{s^3}{3!}G'''_d(0) + \cdots \tag{3}$$

where the prime indicates the derivative with respect to s. Note that truncation of the series up to third-order term is sufficient to set up three independent equations to determine the PID controller parameters.

For an ideal controller, the closed-loop response of the actual system results in the desired closed-loop response. Then by comparison of (2) and (3) we have

$$G_A(0) = G_d(0) \tag{4a}$$

$$G'_A(0) = G'_d(0) \tag{4b}$$

$$G''_A(0) = G''_d(0) \tag{4c}$$

$$G'''_A(0) = G'''_d(0) \tag{4d}$$

The PID controller parameters are to be tuned to satisfy all the equations in (4). Let us first derive the expressions for $G_A(0)$, $G'_A(0)$, $G''_A(0)$ and $G'''_A(0)$ for the actual system with a general transfer function for the process $G_p(s)$. It should be noted that no specific transfer function form is assumed for the process.

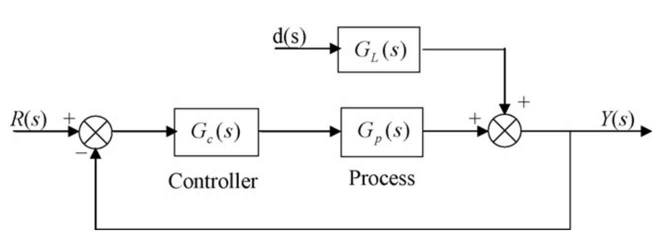

Fig. 1. Block diagram of a feedback control system.