



## Performance assessment and retuning of PID controllers for integral processes

Massimiliano Veronesi, Antonio Visioli \*

Dipartimento di Elettronica per l'Automazione, University of Brescia, Via Branze 38, I-25123 Brescia, Italy

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### ABSTRACT

In this paper we propose a methodology for the performance assessment of a PID controller applied to an integral process and for the retuning of the parameters in case the obtained response is not satisfactory. The technique addresses both set-point and load disturbance step responses. Simulation and experimental results obtained with a laboratory scale equipment show the effectiveness of the methodology.

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### 1. Introduction

Integral (non-self-regulating) processes are frequently encountered in the process industry and their control has been widely investigated by researchers. In particular, many Proportional–Integral–Derivative (PID) tuning rules have been devised [1] for this kind of processes which requires a special attention because of their lack of asymptotic stability. Usually, in the industrial context, there is the need to address a specific control specification, such as set-point following or load disturbance rejection, by ensuring at the same time a satisfactory level of robustness and a reasonable control activity. In spite of the presence of autotuning functionalities [2,3], however, it is also recognised that in many practical cases PID controllers are poorly tuned because of the lack of time and of the lack of skill of the operator. It is therefore important, especially in large plants with hundreds of control loops, to have automatic tools that are first able to assess the performance of a PID controller and, in case it is not satisfactory, to suggest new appropriate values of the controller parameters.

In this paper we propose a methodology for the assessment of the tuning of a PID controller for an integral process based on a routine operating data (namely, by evaluating a set-point or load disturbance closed-loop step response). The performance is evaluated by comparing it with that provided by an appropriate tuning rule which is selected because it provides a small integrated absolute error and an acceptable level of robustness at the same time. If it is determined that the performance can

be improved, then the process parameters are estimated by employing the same routine data and a new tuning is determined.

It is worth stressing that here we refer to the assessment of a deterministic performance (while stochastic performance assessment deals with the capability of the control system to cope with stochastic disturbances [4–7]), namely, we take into account traditional design specifications such as set-point and load rejection disturbance step response parameters [8,9].

In this context, many solutions, addressing different features of a control systems, have been proposed in the literature [10–16] (see [17] for a comprehensive description), but a technique that addresses the PID tuning of an integral process has not been proposed yet. The strategy proposed in this paper has the same rationale as the strategy proposed in [18] for self-regulating processes, namely, the performance obtained with given controller parameters is compared with that obtainable by employing a predefined tuning rule (which is here selected depending on the control task). It is worth noting, however, that here both the set-point following and the load disturbance rejection tasks are addressed, the selected reference tuning rules are (obviously) different, the estimation of the process parameters is based on a different signal and the retuning of the controller is performed by using explicit formulae instead of using an iterative procedure.

### 2. Problem formulation

We consider the unity-feedback control system of Fig. 1 where the integral process  $P$  is controlled by a PID controller whose transfer function is in series (“interacting”) form:

\* Corresponding author. Tel.: +39 030 3715460; fax: +39 030 380014.  
E-mail address: [antonio.visioli@ing.unibs.it](mailto:antonio.visioli@ing.unibs.it) (A. Visioli).

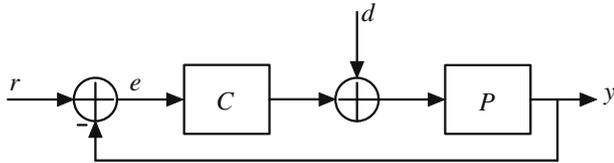


Fig. 1. The control scheme considered.

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

where  $K_p$  is the proportional gain,  $T_i$  is the integral time constant, and  $T_d$  is the derivative time constant. The series form has been chosen for the sake of simplicity, as the tuning rules that will be employed in the methodology apply directly to this form. However the use of other forms is straightforward by suitably applying translation formulae to determine the values of the parameters [17]. Note also that the use of a first-order filter that makes the controller transfer function proper has been neglected for the sake of clarity but it can be easily selected so that it does not influence the PID controller dynamics significantly (and it filters the high-frequency noise at the same time).

The aim of the proposed methodology is to evaluate the closed-loop system response when a set-point or a load disturbance step occurs and to assess the tuning of the PID controller. Then, new PID parameters are determined if the performance is not satisfactory, that is, the PID controller is retuned. For the sake of simplicity, and without loss of generality, we will consider that the step signal is applied starting from null initial conditions. In order to apply the proposed methodology, relevant process parameters have to be estimated. For this purpose, we consider the model reduction technique known as the “half rule”, which states that the largest neglected (denominator) time constant is distributed evenly to the effective dead time and the smallest retained time constant [19]. In practice, the following (possibly high-order) process transfer function is considered:

$$P(s) = \frac{\mu}{s \prod_i (\tau_{i0} s + 1)} e^{-\theta_0 s}, \quad (2)$$

where the time constants are ordered according to their magnitude (namely,  $\tau_{10} > \tau_{20} > \dots$ ). Then, a second-order-plus-dead-time (SOPDT) transfer function

$$\tilde{P}(s) = \frac{\mu}{s(\tau_1 s + 1)} e^{-\theta s} \quad (3)$$

is obtained by setting

$$\tau_1 = \tau_{10} + \frac{\tau_{20}}{2}, \quad \theta = \theta_0 + \frac{\tau_{20}}{2} + \sum_{i \geq 3} \tau_{i0}. \quad (4)$$

It is worth noting that, differently from [19], the presence of positive zeros is not considered in (2). However, the associated time constants can be simply added to the dead time of the process [19].

It is worth stressing that we have

$$T_0 := \sum_i \tau_{i0} + \theta_0 = \tau_1 + \theta, \quad (5)$$

namely, the sum of the dead time and of the time constants of the process (2) is unaltered in the reduced model. Thus,  $T_0$  is a relevant process parameter that is worth estimating for the purpose of the retuning of the PID controller, as will be shown in the following sections.

### 3. Methodology

The assessment of the performance of a control loop is generally performed by first calculating a performance index based on the available data and then by evaluating the current control performance against a selected benchmark, which represents the desired performance [10]. Usually, minimising the integrated absolute error

$$IAE = \int_0^{\infty} |e(t)| dt = \int_0^{\infty} |r(t) - y(t)| dt \quad (6)$$

is meaningful because this yields, in general, a low overshoot and a low settling time at the same time [20]. However, aiming at obtaining the theoretical minimum integrated absolute error that can be achieved for a single-loop system might not be sensible in practical cases because the robustness issue and the control effort have also to be taken into account.

If only the set-point following task is of concern, the desired performance selected in this paper is that obtained by applying the Internal Model Control (IMC) approach [21] which, if applied to the process (3) where the dead time is approximated as  $e^{-\theta s} = 1 - \theta s$ , yields a PD controller whose parameters are selected according to the following tuning rule:

$$K_p = \frac{1}{2\mu\lambda}, \quad T_d = \tau_1, \quad (7)$$

where  $\lambda$  is the selected closed-loop time constant and can be selected as  $\lambda = \theta$  according to the well-known SIMC tuning rules [19] which aim at providing a good robustness to the control system. With this PD controller and with the same approximation as before for the dead time term, the closed-loop transfer function results:

$$F(s) := \frac{Y(s)}{R(s)} = \frac{C(s)\tilde{P}(s)}{1 + C(s)\tilde{P}(s)} \cong \frac{e^{-\theta s}}{1 + \theta s} \quad (8)$$

for which the integrated absolute error when a step signal of amplitude  $A_r$  is applied to the set-point is

$$IAE_{sp} = \int_0^{\infty} |e(t)| dt = 2A_r\theta. \quad (9)$$

Thus, a sensible index, named Closed-loop Index  $CI$ , to evaluate the controller performance with respect to the set-point following task is:

$$CI_{sp} = \frac{2A_r\theta}{\int_0^{\infty} |e(t)| dt}. \quad (10)$$

In other words, the obtained integrated absolute error is compared with the one that would be achieved if a PD controller tuned according to the IMC tuning rules (7) with  $\lambda = \theta$  is applied to the process (3).

In principle, the performance obtained by the control system is considered to be satisfactory if  $CI_{sp} = 1$ . From a practical point of view, however, the controller is considered to be well-tuned if  $CI_{sp} > \bar{CI}_{sp}$  with  $\bar{CI}_{sp} = 0.6$ . This last value has been selected by considering the (S)IMC tuning rule applied to many different processes [19] but, in any case, another value of  $\bar{CI}_{sp}$  can be selected by the user depending on how tight are its control specifications. Actually, selecting an empirical target value is a standard practice in control loop performance assessment (see, for example, [14]).

If both the set-point following and the load disturbance rejection are of concern in the control task, the integral action has to be employed in order to achieve a null steady-state error in the presence of a constant load disturbance and the desired performance is selected as the one obtained by applying the SIMC tuning rule [19]:

$$K_p = \frac{1}{2\mu\theta}, \quad T_i = 8\theta, \quad T_d = \tau_1. \quad (11)$$

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