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Tuning rules for optimal PID and fractional-order PID controllers

Fabrizio Padula, Antonio Visioli *

Dipartimento di Ingegneria dell'Informazione, University of Brescia, Via Branze 38, I-25123 Brescia, Italy

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ABSTRACT

In this paper we present a set of tuning rules for standard (integer-order) PID and fractional-order PID controllers. Based on a first-order-plus-dead-time model of the process, the tuning rules have been devised in order to minimise the integrated absolute error with a constraint on the maximum sensitivity. The achieved performance indexes can also be used for the assessment of the controller performance. Both set-point following and load disturbance rejection tasks are considered. By comparing the results obtained for the two kinds of controllers, it is shown that the use of fractional-order integral action is not advantageous, while the use of a fractional-order derivative action provides a performance improvement.

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1. Introduction

Fractional-order proportional-integral-derivative (FOPID) controllers have received a considerable attention in the last years both from an academic and industrial point of view (see, for example [1–5]). In fact, *in principle*, they provide more flexibility in the controller design, with respect to the standard PID controllers, because they have five parameters to select (instead of three). However, this also implies that the tuning of the controller can be much more complex. In order to address this problem, different methods for the design of a FOPID controller have been proposed in the literature. They are based on the use of evolutionary algorithms, where different objective functions are considered [6–8], or on the solution of a nonlinear constrained optimisation problem where, in particular, the iso-damping property (namely, the robustness to variations in the gain of the process) is considered [9–11].

It is however recognised that, for their widespread use in industry, FOPID controllers should possess the same ease of use of standard PID controllers and the improvement in the performance they are capable to provide should be clear. Actually, one of the reasons of the great success of standard PID controllers is the presence of a lot of tuning rules [12] and of the automatic tuning feature [13] that simplify significantly their design. For this reason, tuning rules for FOPID controllers have been proposed in the literature. In [14,15] they have been developed in order to achieve the iso-damping property. However, they are not general because they are valid only for first-order-plus-dead-time (FOPDT) processes with specific values of the time constant and of the dead time, and the gain cross-over frequency is selected *a priori*. A more general tuning rule, which is valid for every FOPDT process, based on the fractional maximum sensitivity constrained integral gain optimisation method has been proposed in [16]. However, the technique is restricted to PI controllers. Finally, with the aim of minimising the effects of low frequency load disturbances, another set of tuning rules has been developed in [17,18]. Indeed, it has to be remarked that the load disturbance rejection task is often overlooked in the literature related to fractional order controllers, despite this task is often of main concern in the process industry.

In this paper we propose a new set of tuning rules for PID and FOPID controllers based on the minimisation of the integrated absolute error (which is meaningful because this yields, in general, a low overshoot and a low settling time at the same time [19]), subject to a constraint on the maximum sensitivity (as in the well-known Kappa–Tau tuning rules for standard PID controllers [20]) in order to provide a required level of robustness. It will be shown that, in this context, if the controller is restricted to a PI structure, then the use of a fractional integral action is not useful in improving the performance and therefore a standard PI controller is the best option. Conversely, the use of a fractional derivative action allows to improve the control performance. Both the set-point following and the load disturbance rejection tasks will be considered explicitly. An analytical expression of the performance index is also given and this can be exploited in a performance assessment context.

The paper is organised as follows. In Section 2 the problem is formulated. The tuning rules are described in Section 3. Simula-

* Corresponding author. Tel.: +39 030 3715460; fax: +39 030 380014.
E-mail addresses: fabrizio.padula@ing.unibs.it (F. Padula), antonio.visioli@ing.unibs.it (A. Visioli).

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