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Design and tuning of a ratio controller ☆

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Abstract

In this paper a design and tuning procedure for a ratio control architecture is proposed. The overall control scheme is based on the use of the Blend station proposed in (Control Eng. Pract. 9 (11) (2001) 1215) and standard PI controllers. Since all the control parameters can be automatically selected based on a simple model of the process under control, the proposed methodology is easy to implement and therefore suitable to be applied in the industrial context. Simulation and experimental results show the effectiveness of the methodology for a wide range of processes.

Keywords: Ratio control; Auto-tuning; PID controllers; Blending

1. Introduction

Proportional-integral-derivative (PID) controllers are the controllers most adopted in industry due to the good cost/benefit ratio they are able to provide for a wide range of processes. Often, they are employed as basis of more complex control schemes where couplings between simple control systems are exploited. An example is ratio control, which consists of keeping a constant ratio between two process variables. This is actually required in many applications, such as chemical dosing, water treatment, chlorination, mixing vessels, waste incinerators. For example, in combustion systems the air-to-fuel ratio has to be controlled to obtain an high efficiency, and in blending processes a selected ratio of different flows has to be maintained to keep a constant product composition.

In the last 60 years, a major effort has been provided by researchers to develop useful techniques for the implementation of the basic PID algorithm (tuning and automatic tuning methods) and of additional functionalities such as anti-windup, gain scheduling, adaptive control and so on (Åström & Hägglund, 1995). Recently, this effort has been further motivated by the increase of the computational capability which is available in modern single-station industrial controllers and distributed control systems (DCS). Conversely, the design of methodologies for the implementation of the above mentioned basic couplings has been much overlooked. Obviously, to be suitable for industrial settings, in addition to the achievement of high performances, the ease of understanding and of use of new techniques is a major requirement.

A relevant recent work in this context is the one of Hägglund (2001) in which a new ratio control structure is proposed. Based on this control scheme, in this paper a design methodology for a ratio controller is proposed. A salient feature of the proposed method is that all the control parameters are selected based on simple models obtained by accomplishing standard identification experiment, and therefore the overall method can be easily performed automatically. The paper is organised as follows. In Section 2, a short introduction of ratio control is provided and Hägglund's Blend station is briefly reviewed. In Section 3, the new ratio control architecture is proposed. The tuning procedure is revealed in Section 4. Simulation results are presented and discussed in Section 5, whilst experimental results obtained with a laboratory equipment are shown in Section 6. Finally, conclusions are drawn in Section 7.

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2. Ratio control and the Blend station

The aim of a ratio control system is to keep the ratio between the values of two process variables y_1 and y_2 equal to a constant value a, in order to meet some higher-level requirements. For this purpose, the control scheme shown in Fig. 1 is usually implemented. Each variable is controlled by two separate controllers C_1 and C_2 (typically of PI type) and the output y_1 of the first process is multiplied by a and adopted as the set-point of the closed-loop control system of the second process, i.e. it is $r_2(t) = ay_1(t)$ (Shinskey, 1996). In this way, at the steady state, provided that the gain of the second loop is equal to unity (note that this condition is normally verified by the presence of the integral part in the controller) the requirement

$$\frac{y_2(t)}{y_1(t)} = a$$

is satisfied.

The main disadvantage of this scheme is related to the transient response to a change in the set-point r_1, as the output y_2 is necessarily delayed with respect to y_1, due to the closed-loop dynamics of the second loop. To overcome this drawback, Hägglund proposed an alternative architecture, named the Blend station (Hägglund, 2001). This is shown in Fig. 2. The main feature of the scheme is that the value of the set-point r_2 depends both on the value of the process output y_1 and on the value of the set-point r_1, according to the expression

$$r_2(t) = a(\gamma r_1(t) + (1-\gamma)y_1(t)). \tag{1}$$

Note that γ is a constant parameter that weights the relative influence of the set-point r_1 on r_2 with respect to y_1 (for $\gamma = 0$ the classical scheme of Fig. 1 is obtained).

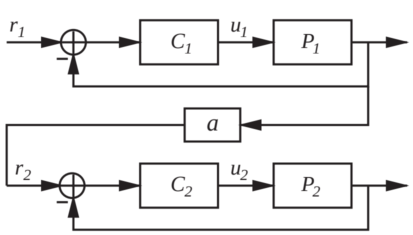

Fig. 1. The typical ratio control scheme.

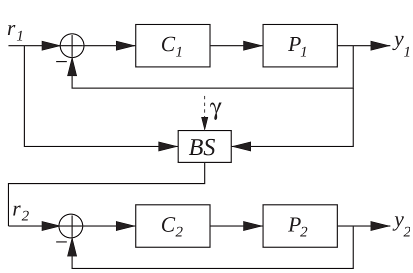

Fig. 2. The ratio control scheme using the Blend station.

The value of γ can be selected as the ratio of the time constants of the two closed-loop systems (or, if they are not available, as the ratio of the integral time constants of the two controllers) or, alternatively, by applying a suitable adaptive procedure, i.e. by applying the following formula (Hägglund, 2001):

$$\frac{d\gamma}{dt} = \frac{S}{T_a}(ay_1 - y_2), \tag{2}$$

where $S \in \{-1, 0, 1\}$ is a sign parameter that takes into account if the set-point step is positive or negative. In (Hägglund, 2001) it is suggested to select the value of the adaptation rate T_a as a factor times the longest integral time of the two loops. Note that, for the two PI controllers, explicit tuning rules to be adopted in this context are not given.

3. The new ratio control architecture

The ratio control architecture proposed in this paper is based on the Blend station but aims at achieving better transient responses by adopting a time-varying parameter $\gamma(t)$. Assume that a transition from the initial value y_1^i to the final value y_1^f is required to be performed at time $t = t_0$ from the process variable y_1 (i.e. a step set-point signal of amplitude $y_1^f - y_1^i$ is applied to the set-point signal $r_1(t)$ at time $t = t_0$). Without loss of generality, in the following it will be assumed that a positive step signal is applied, i.e. $y_1^f > y_1^i$. First, the second loop, has to be selected as the one with the fastest dynamics, i.e. the dynamics of process P_2 is faster than the one of P_1. This is actually the obvious choice in the typical ratio control scheme of Fig. 1, as the output of process P_2 (appropriately scaled) can follow easier the one of process P_1 as requested.

Processes P_1 and P_2 are modelled with first order plus dead time (FOPDT) transfer functions:

$$P_1(s) = \frac{K_1}{T_1 s + 1} e^{-L_1 s}, \tag{3}$$

$$P_2(s) = \frac{K_2}{T_2 s + 1} e^{-L_2 s}. \tag{4}$$

This choice is motivated by the fact that the dynamics of many industrial processes can be well-captured by a FOPDT model and that in any case, the knowledge of a higher-order model cannot be significantly exploited in the synthesis of a simple PI controller (Åström & Hägglund, 1995). Actually, obtaining a high-order model of a plant and adopting it in the design of a controller might prevent the good cost/benefit ratio that is the main reason of the extensive use of PI(D) controllers in industrial settings. However, it should be stressed that whereas a second-order plus dead time (SOPDT) model is available, the controller can be selected of PID type, where a zero of the controller is