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Tuning of multi-loop PI controllers based on gain and phase margin specifications☆

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ABSTRACT

In this paper, a single-iteration strategy is proposed for the design of a multi-loop PI controller to achieve the desired gain and phase margins for two-input and two-output (TITO) processes. To handle loop interactions, a TITO system is converted into two equivalent single loops with uncertainties drawn from interactions. The maximum uncertainty is estimated for the initial controller design in one loop and single-input and single-output (SISO) controller design is applied. This controller is substituted to other equivalent loop for design, and finally, the first loop controller is refined on knowledge of other loop controller. For SISO controller tuning, a new method is presented to determine the achievable gain and phase margins as well as the relevant controller parameters. Examples are given for illustration and comparison.

1. Introduction

Gain and phase margins are often used as performance specifications to tune PID controllers for SISO industrial systems [1–3]. The main reason for this is that the gain and phase margins have served as important measures of stability robustness in control loop, unlike the H_∞, H_2, l^1, and μ methods which often lead to fragile controllers [4]. In the well-known design procedure due to Astrom's [5] method, the ultimate gain and frequency are estimated by a relay test and a controller calculated with simple formulas. Ho et al. [6] presented a tuning method based on a simplified first-order plus dead time model. Unlike such simple models, Fung et al. [7] proposed a graphical method for PI controller tuning for any linear system, where exact margins can be accomplished regardless of the process order, time delay or damping nature. However, this method may have no solution unless the gain and phase margin are chosen properly a priori to get a solution.

Most processes in industry are of multiple-inputs and multiple-outputs (MIMO) nature. Decentralized control is popular for MIMO systems as it has simple structure and fewer tuning parameters to handle [8,9] and becomes an active research topic for years [10–12]. Independent design and sequential design are two common design strategies in decentralized control [13–15]. But the former ignores loop interactions whereas the latter needs a lot of SISO design iterations. MIMO decentralized control design is complicated because of the interactions between control loops [16], especially for gain and phase margin specifications where even the SISO case usually has no analytical solution. In the context of MIMO gain and phase margins, Ho et al. [17] proposed a tuning method based on Gershgorin bands and SISO gain and phase margins design is applied to the band of each loop. However, Kookos [18] pointed out that this method works only when the open-loop system is column dominant. Huang et al. [19] used equivalent single loops together with effective open-loop processes (EOPs) to derive multi-loop PI/PID controllers. In this method, model reductions and approximations are necessary to obtain EOPs, which will bring design error inevitably.

In this paper, we develop a single-iteration strategy to design controllers loop by loop for a TITO process which is the most common multivariable system in industry [20,21]. We design an initial controller in one loop based on some uncertainty estimation due to the unknown 2nd loop controller; and then other loop's controller with the known first-loop controller; Finally, we re-tune the first-loop controller with the known 2nd-loop controller. With the

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