JCSE International Journal of Computer Sciences and Engineering Open Access

Research Paper Vol.-7, Special Issue-10, May 2019 E-ISSN: 2347-2693

Estimation of Underdamped Overshoot in Second-Order Control Systems

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DOI: https://doi.org/10.26438/ijcse/v7si10.97100 | Available online at: www.ijcseonline.org

Abstract**—** The paper investigates the problem of overshoot estimation decreasing for underdamped second-order control systems. A new technique to control the overshoot is proposed, which is based on Posicast control and proportional integral and derivative (PID) control, which performs switching between two controllers. The aim is to use open-loop feedforward control to increase tracking performance and PID control to deal with disturbance rejection. It has been shown that the proposed control scheme can have some advantages over the classical approaches without switching capabilities.

Keywords**—** *PID control, Posicast control, Second-order systems, Anti-windup*

I. INTRODUCTION

A deadbeat-response is often considered as an optimal closed-loop response, since it achieves minimum rise-time, no steady-state error and no overshoot, in a minimum number of time-steps. From the authors' experience in designing second-order systems control, an important question is: how to achieve small or zero overshoot in the closed-loop step-response for the second-order systems? This is a relevant issue, as there are many control applications in practice dealing with systems dynamics represented by second order models and requiring minimum overshoot. The representatives of such systems can be found in robot control (Singhose and Seering, 2005), crane control (Sorensen et al., 2007) vibration control (Singer and Seering, 1990; Singhose, 2009; Singh and Singhose, 2002; Dhanda and Franklin, 2005) and power-systems electronics (Li, 2009; Chiang et al., 2009).

Proportional–integral (PI) and proportional–integral–derivative (PID) controllers are most commonly used in industrial processes, owing to their satisfactory control effect, acceptable robustness, and simple control structure [1]. According to [2], it is estimated that over 90% of control loops employ PID controllers and, on many occasions, with the derivative gain set to zero (i.e., PI control). By and large, PI and PID have been the classic type of controllers since mid-20th century, and they continue as the most often used control scheme [3]. As it was concluded at the International Federation of Automatic Control Conference on Advances in PID control in 2012, PID/PI controllers will remain as the main implemented control algorithms, in spite of other promising proposals, such as model predictive control paradigms [4]. However, as shown in several surveys, there is a lack of engagement between the industrial world and the academic community.

II. RELATED WORK

Since the PID controller tuning rules of Ziegler and Nichols (1942), different and new approaches have been developed, mainly concerned with feedback controllers tuned either for a well-damped fast response to a step change in the controller set-point, or emphasizing the importance of disturbance rejection in the design. Some of the developed methods considered only the system performance, by using an integrated error criteria (Integral Absolute Error (IAE), Integral Square Error (ISE) or Integral Time Absolute Error (ITAE). as, for example, the pioneering methodologies developed by Murrill et al. (1967) or Rovira et al. (1969), or the more recent work by Awouda and Mamat (2010). Conversely, other developed tuning rules consider mainly the robustness, such as AMIGO (Approximate M constrained Integral Gain Optimization) developed by Åström and Hägglund or those developed by Ho et al. Another relevant research line is the set of tuning rules that proposes a tradeoff between performance and robustness, or between servo and regulation modes. There are also tuning rules specifically developed for unstable FOPTD processes, ranging from relatively simple analytic tuning formulae to more complex techniques using evolutionary or heuristic algorithms. Nevertheless, as mentioned before, a great majority of tuning rules is based on FOPTD models, and there are extensions to other structures, such as the second order plus dead time (SOPDT), the integrator plus dead time (IPDT), and the first order and integrator plus dead time (FOIDT). The number of developed tuning rules based on the FOPT.

III. METHODOLOGY

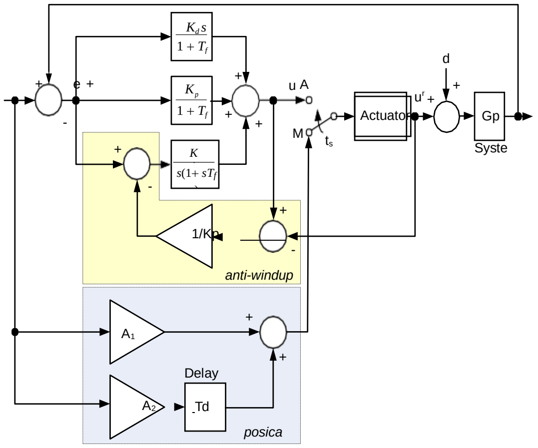
Most of the industrial control loops are controlled either by proportional and integral (PI) controllers or by proportional, integral and derivative (PID) controllers (Åström and Hägglund, 1995) due to a relatively high performance and robustness levels achieved in a wide range of plants. This type of controllers can be represented and implemented using several control configurations (Araki and Taguchi, 2003). This study considers PID control implemented with output filter, since controller output activity is significantly reduced in noisy systems. The PID controller adopted can be represented by:

$$G_c(s)=\frac{s^2K_d+sK_p+K_i}{s}\left(\frac{1}{1+sT_f}\right)$$

Where: K_p, K_i and K_d represent the proportional, integral and derivative term gains, respectively, and T_f the filter time constant.

A myriad of techniques have been proposed to solve the windup problem (Peng et al., 1996; Zaccariana and Telb, 2002; Visioli, 2006), known as anti-windup or reset-windup techniques. Windup occurs as a practical limitation associated with all actuators, its saturation limits, which cause the controller integral part to increase significantly,

The structure used to control underdamped second-order systems is represented in figure 2. The principle of the control structure is to use a half-cycle Posicast as feedforward control to achieve deadbeat response, in accordance to desired set- point tracking, and PID Control to deal with disturbance rejection. Structure in figure 2 has an advantage over structure in figure 1, since it improves the set-point tracking performance. Disadvantage is that the system is in the open- loop configuration during set-point change. However, set- point changes are usually not frequent in industrial applications



b)

Fig. 1. Feedforward-feedback configurations. a) The half cycle Posicast is used as a prefilter b) Equivalent configuration to a).

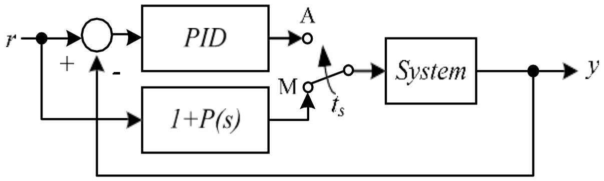


Fig. 2. Feedback control loop with the shaper used for setpoint tracking and the controller for disturbance rejection.

Figure 3 presents the proposed control structure in which the half-cycle Posicast shaper is used in an open-loop or manual (M) mode to perform set-point tracking, and the operation is changed to an automatic mode (A) to achieve disturbance rejection. This control structure uses an anti-windup and bumpless transfer protection by using the Conditioning technique (Hanus et al., 1987; Walgama et al., 1992; Bohn and Atherton,1995; Peng et al.,1996). The actuator amplitude and velocity limits are represented by a model. The controller with anti-windup protection is denoted as:

$$U=G_r(s)R-G_c(s)Y-G_{AW}(s)(U-U^r)$$

where U, U^r, R and Y are controller output, limited output, reference and the process output, respectively. G_{AW} is anti-windup protection. The anti-windup protection is realised by feeding amplified difference between signals U and U^r back to integrator's input, as shown in Figure 3.

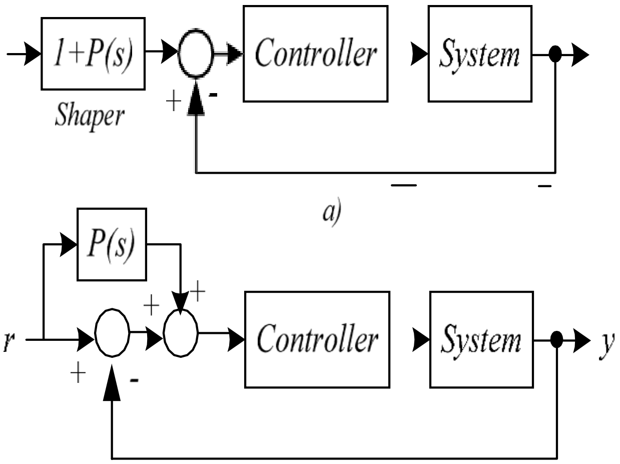


Fig. 3. Proposed feedback loop with: PID controller, Posicast and anti-windup protection

IV. RESULTS AND DISCUSSION

Figure 4 presents the system output response to a unit step input signal obtained with three control structures: the PID controller, the PID controller with the half-cycle Posicast (PID-P) and the PID controller with anti-windup protection and the half-cycle Posicast (PID-AW-P), using the control implementation presented in Figure 3. The switching time equals settling time of the process. In this case the switch in figure 3 changes to automatic mode (PID closed-loop control) at t=4s. A step input disturbance with amplitude of 0.2 has

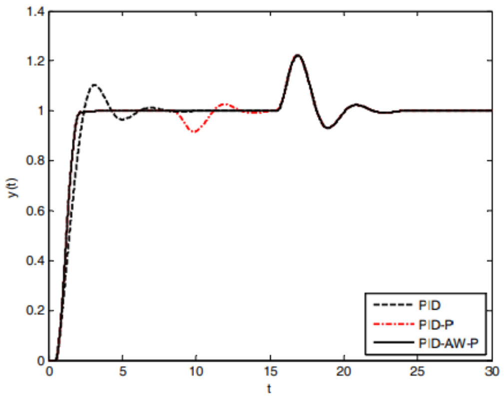


Fig. 4. System output step response obtained with the PID controller, PID with half-cycle Posicast and the bumpless PID control configuration presented in Fig. 3.

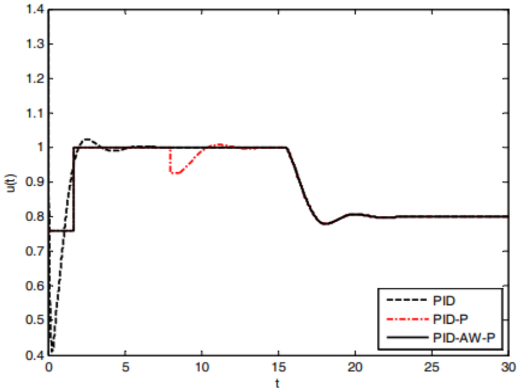


Fig. 5. Control signal output for the step responses presented in Fig. 4.

As it can be seen from Fig. 5, there is a relatively large change of controller output signal when switching into automatic mode with PID-P controller. On the other hand, anti-windup protection was more than efficient when using PID-AW-P controller, since there was no large change of control signal. The results indicate that the proposed methodology clearly improve the set-point tracking performance of the underdamped control system due to the Posicast compensator, while maintaining the regulatory performance of the PID controller.

V. CONCLUSION AND FUTURE SCOPE

In this paper a new proposed which integrates the half- cycle shaper as a feedforward compensator to increase tracking performance and a PID controller to retain disturbance rejection properties. The transition between the manual feedforward set-point operation and automatic feedback PID control is accomplished by using an appropriate anti-windup and bumpless transfer technique. The proposed solution is especially efficient for decreasing the overshoots of underdamped second-order systems. Simulation results clearly indicate that the Posicast technique significantly improves the set-point tracking performance compared to the PID controller.

The proposed control structure can be easily implemented and has a great margin for improvement. The issue of model parameter uncertainty is to be addressed in future research.

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