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Tuning of a PDF controller used with a very slow second-order process

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ABSTRACT

A second order process of 164.5 seconds settling time is controlled using a PDF controller (through simulation). The controller is tuned by minimizing the sum of square of error of the control system using MATLAB. Functional constraints are imposed on the maximum percentage overshoot, settling time and stability condition. The result was reforming the process slow response and producing a closed-loop control systems of a maximum percentage overshoot less than 2 % and a settling time less than 0.6. The performance of the tuned-PDF controlled process is compared with that tuned using the ITAE standard forms.

Introduction

Slow processes require intensive work in selecting proper controllers or compensators and in tuning the selected one for better performance of the control system. In this work the PDF-controller introduced by Phelan [1] is suggested to control the slow second order process.

Ohm (1994) used a PDF and PDFF controllers for the purpose of motion control in servo systems [2]. Ellis and Lorenz (1999) studied using PDFF controllers instead of the PI and PDF controllers in motion control applications requiring high performance AC and DC servo-drives [3]. Romeral and Chekkouri (2002) used fuzzy adaptive PDF controller for motion control systems [4]. Fransson and Lennarrton (2003) studied the use of low order multi-criteria H∞ controllers with fourth order processes and a nine states jet engine model. They showed that the PIDF controller worked well with the SISO fourth order processes [5]. Reinhorn et al. (2004) used a PIDF controller in controlling the force acting on a mechanical structure in an innovative scheme for force control [6]. Shen (2006) presented a dynamic stiffness design scheme based on a PDFF controller for linear servo systems [7]. Ganovski (2007) used PD, PDFF and FFCT controllers to control parallel manipulators. He tuned the controllers using the Ziegler-Nichols method and a special performance criterion [8]. Arvanitis, Pasgiano and Kalogeropoulos (2007) described using a pre-filter with PID, P-PID and PDF controllers to control unstable dead-time processes [9]. Otis et al. (2009) used a PIDF controller to control a cable tension using a hybrid position / tension control [10]. Yurkevich (2009) used PI, PID, PIF and PIDF controllers in controlling nonlinear systems [11]. Todorov et al. (2010) used a PIDF controller in the control scheme of a pneumatic robot. They stated that the PIDF controller turns out to be a much better control scheme [12]. Cheng and Li (2011) using moving average errors control to increase the speed of response of a PDFF controller [13]. MathWorks (2012) introduced both PDF and PIDF to the classical controller types P, PI, PD and PID that are supported by MATLAB [14]. Hassaan, Al-Gamil and Lashin (2013) presented a tuning technique for PIDF controllers used with highly oscillating second-order processes. Their tuning scheme was based on the SAE criterion in a constrained optimization technique using MATLAB. They could cancel completely the proves oscillations and generate an overshoot-free time response of the control system associated with a small settling time [15]. Hassaan (2014) studied a simple tuning technique for PID controllers used with over damped second-order processes. He used an ISE criterion and could reduce the controller tuning to only one set of parameters independent of process natural frequency and damping ratio [16].

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Analysis

Process:

The process is a second order process having the parameters:

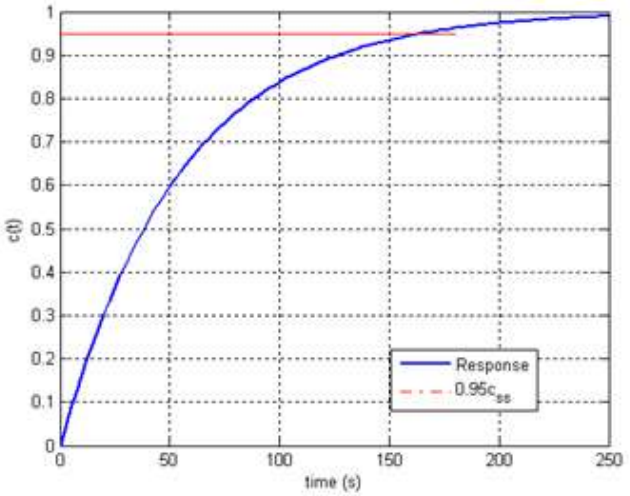
Natural frequency: $\omega_n = 0.4$ rad/s

Damping ratio: $\zeta = 11$

The process has the transfer function:

$$M_p(s) = \omega_n^2 / (s^2 + 2\zeta\omega_n s + \omega_n^2) \qquad (1)$$

The time response of this process to a unit step input is shown in Fig.1 as generated by MATLAB:



The performance of the process is measured by its settling time. It a settling time of 164.55 seconds, i.e. more than 2.7 minutes indicating the slow response of the process to a step reference input.

Controller:

The controller used in this study is a pseudo-derivative feedback (PDF) controller. The PDF-controller has the block diagram shown in Fig.2 [2,3].

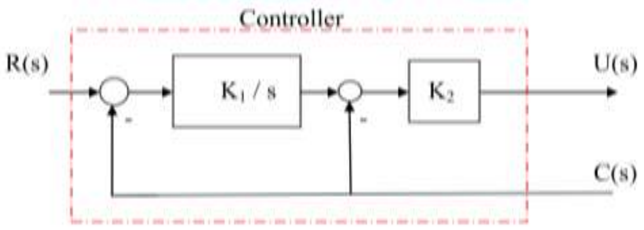


Figure 2. PDF-controller [2,3].

The PDF-controller of Fig.2 has a mathematical model function of the input reference input {R(s)}, controller output {U(s)} and control system output {C(s)}. That is:

$$U(s) = \{(K_1/s)[R(s) – C(s)] – C(s)\} K_2 \quad (2)$$

Where: K_1 = first controller parameter

K_2 = second controller parameter

Control System Transfer Function:

Assuming that the control system is a unit feedback one, the overall block diagram of the closed-loop control system using Eqs.1 and 2 gives the closed-loop transfer function of the system as:

$$M(s) = b_0 / (s^3 + a_1s^2 + a_2s + a_3) \quad (3)$$

where:

$b_0 = K_1K_2\omega_n^2$

$a_1 = 2\zeta\omega_n$

$a_2 = \omega_n^2 (1 + K_2)$

$a_3 = K_1K_2\omega_n^2$

System Step Response:

A unit step response is generated by MATLAB using the numerator and deniminator of Eq. 3 providing the system response c(t) as function of time [17].

Controller Tuning

The sum of square error (ISE) is used as an objective function, F of the optimization process. Thus:

$$F = \int [c(t) – c_{ss}]^2 \, dt \quad (4)$$

where c_{ss} = steady-state response of the system.

The performance of the control system is controlled using three functional constraints:

(a) The maximum percentage overshoot constraint, c_1:

$$c_1 = OS_{max} - OS_{des} \quad (5)$$

Where OS_{des} is the desired maximum percentage overshoot of the control system.

The settling time constraint, c_2:

$$c_2 = T_s - T_{sdes} \quad (6)$$

Where T_{sdes} is the desired settling time of the control system.

The stability constraint:

Using the Routh-Hurwitz criterion for the stability of linear feedback control systems, the third functional constrained , c_3 is defined as:

$$c_3 = a_3 – a_1a_2 \quad (7)$$

Tuning Results:

The MATLAB command "*fmincon*" is used to minimize the optimization objective function given by Eq.4 subjected to the functional inequality constraints given by Eqs. 5 - 7 to provide the controller tuned parameters [18]. The results are as follows:

Controller parameters:

K_1 = 2.7768

K_2 = 452.8423

The time respone of the control system to a unit step input is shown in Fig.3.

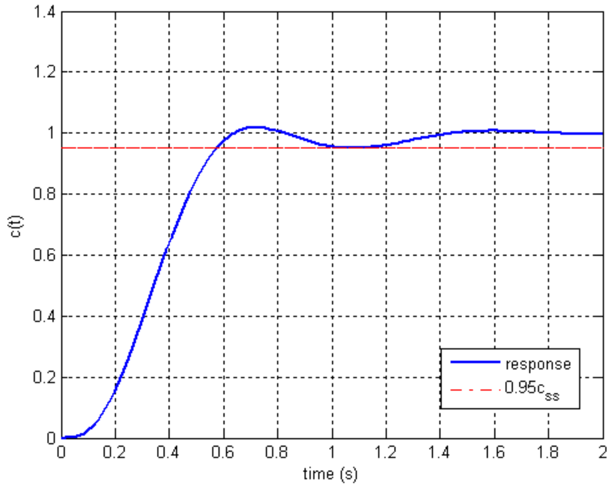


Figure 3. Step response of the PDF controlled second-order process.

Characteristics of the control system using the tuned PDF controller:

- Maximum percentage overshoot: 1.84 %
- Settling time: 0.57 s

Comparison with Standard Forms Tuning

According to the work of Graham and Lathrop [19], the optimal standard form of a control system having a transfer function of Eq.3 is:

$$s^3 + 1.75\omega_o s^2 + 2.15\omega_o^2 s + \omega_o^3 = 0 \quad (8)$$

Comparing the coefficients of the system characteristc equation in Eqs.3 and 8 gives the PDF-controller parameters as:

K_1 = 2.4144

K_2 = 359.0692

The time response of the control system using the present tuning of the PDF controller and the standard forms tuning is shown in Fig.4.

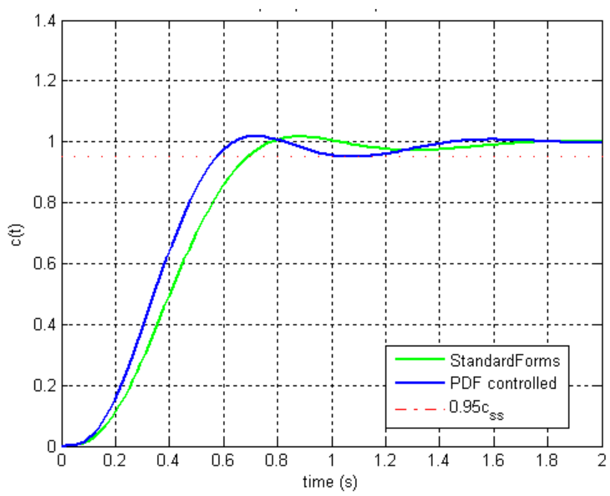


Figure 4. Step response comparison.

Characteristics of the control system:

- Maximum percentage overshoot: 1.840 % (compared with 1.666 % using the standard forms tuning).
- Settling time: 0.573 s (compared with 0.687 s using the standard forms tuning).

Conclusions

- It is possible to increase the speed of the process response through using the PDF-controller.

- Through using a PDF controller it was possible to reduce the settling time from about 145.6 seconds to about 0.57 seconds indicating the fast settlement of the controlled process.
- The proposed tuning approach of the PDF-controller was comparable with the tuning results using the standard forms.
- The maximum percentage overshoot was greater than that using the standard forms by 10 % .
- The settling time was less than that using the standard forms by 16 %.

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Biography

Galal Ali Hassaan:

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