Tuning of a PDFF Controller used with a Very Slow Second Order Process

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Abstract

Slow response of physical processes represents a dynamic problem and has to be solved through automatic control engineering by selecting reasonable controllers or compensators. A PDFF controller is proposed in this work to overcome the slow response dynamic problem. The controller is tuned using an IAE objective function and three functional constraints controlling the time-based specifications of the closed-loop control system and maintaining a stable linear control system during the optimization process.

A second order process of 164.5 seconds settling time is controlled using a PDFF controller (through simulation). The controller is tuned by minimizing the sum of absolute 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 of 0.72 % and a settling time of 0.77 seconds. The performance of the tuned-PDFF controlled process is compared with that tuned using the ITAE standard forms and with control using a PID-controller.

Keywords

PDFF controller – very slow second order process – controller tuning – IAE objective function – MATLAB optimization – improved control system performance.

I. 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 use of PDFF-controller which is an extension of the PDF-controller is investigated to control the slow second-order process.

Ohm (1994) used a PDF and PDFF controllers for the purpose of motion control in servo systems [1]. 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 [2]. Romeral and Chekkouri (2002) used fuzzy adaptive PDF controller for motion control systems [3]. 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 [4]. Reinhorn et al. (2004) used a PIDF controller in controlling the force acting on a mechanical structure in an innovative scheme for force control [5]. Shen (2006) presented a dynamic stiffness design scheme based on a PDFF controller for linear servo systems [6]. 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 [7]. Arvanitis , Pasgiano and Kalogeropoulos (2007) described using a pre-filter with PID, P-PID and PDF controllers to control unstable dead-time processes [8]. Otis et al. (2009) used a PIDF controller to control a cable tension using a hybrid position / tension control [9]. Yurkevich (2009) used PI, PID, PIF and PIDF controllers in controlling nonlinear systems [10].

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 [11]. Cheng and Li (2011) using moving average errors control to increase the speed of response of a PDFF controller [12]. MathWorks (2012) introduced both PDF and PIDF to the classical controller types P, PI, PD and PID that are supported by MATLAB [13]. Hassaan, Al-Gamil and Lashin (2013) tuned a PIDF controller for a second-order process of 85.4 % maximum percentage overshoot by minimizing the sum of absolute error (SAE) using MATLAB. They succeeded to cancel completely the process oscillation and reduce the settling time to only 0.6 s [14]. Hassaan (2014) presented a simple tuning approach for PID controllers used with overdamped second-order processes of damping ratio from 1 to 10. He tuned the controller using the integral of absolute error (ISE) criterion and succeeded to reduce the tuning process to only one set of parameters independent of process damping ratio and natural frequency [15]. Hassaan (2014) tuned a classical PD controller used with second-order-like processes having damping ratio from 0.05 to 10. He used the ISE criterion to control the controller. He tabulated the results against process damping ratio and natural frequency. The time response of the control system was superior when compared with another tuning technique [16].

II. Analysis

A. 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.

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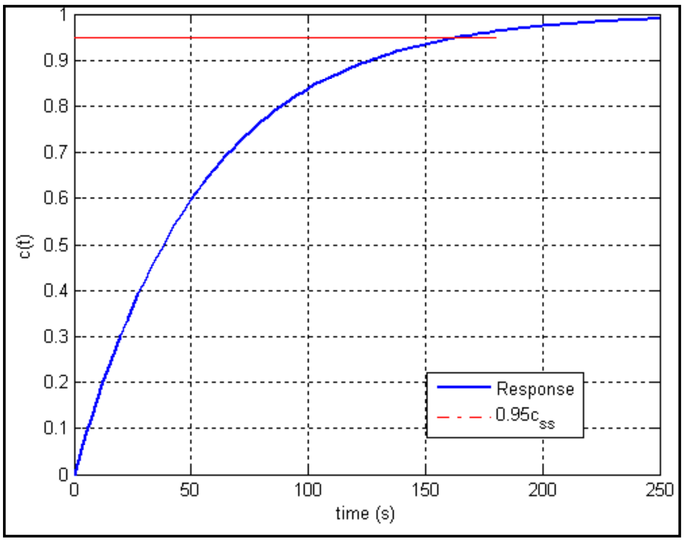

Fig.1: Step response of the uncontrolled process.

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.

B. Controller

The controller used in this study is a pseudo-derivative feedback (PDF) controller with feedforward term. The PDFF-controller has the block diagram shown in Fig.2 [17].

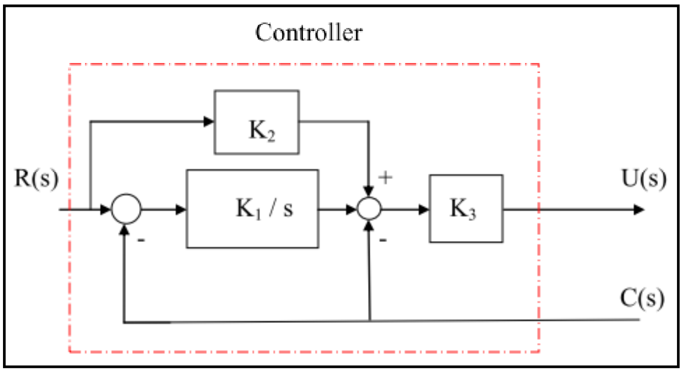

Fig.2 : PDFF controller [17].

The PDFF-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:

$$U(s) = \{(K_1/s)[R(s) - C(s)] + K_2R(s) - C(s)\}\ K_3 \qquad (2)$$

Where: K_1 , K_2 and K_3 are the PDFF-controller parameters

C. 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:

$$M(s) = (b_0s + b_1) / (s^3 + a_1s^2 + a_2s + a_3) \qquad (3)$$

where:

$$b_0 = K_2K_3\omega_n^2$$
$$b_1 = K_1K_3\omega_n^2$$
$$a_1 = 2\zeta\omega_n$$
$$a_2 = \omega_n^2 (1 + K_3)$$
$$a_3 = K_1K_3\omega_n^2$$

D. 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.

III. Controller Tuning

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

$$F = \int |c(t) - c_{ss}|\ dt \qquad (4)$$

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

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

The maximum percentage overshoot constraint, c_1:

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

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

The settling time constraint, c_2:

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

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:

$$c_3 = a_3 - a_1a_2 \qquad (7)$$

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 [18]. The results are as follows:

Controller parameters:

K_1 = 2.6858
K_2 = 0.4336
K_3 = 908.9370

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

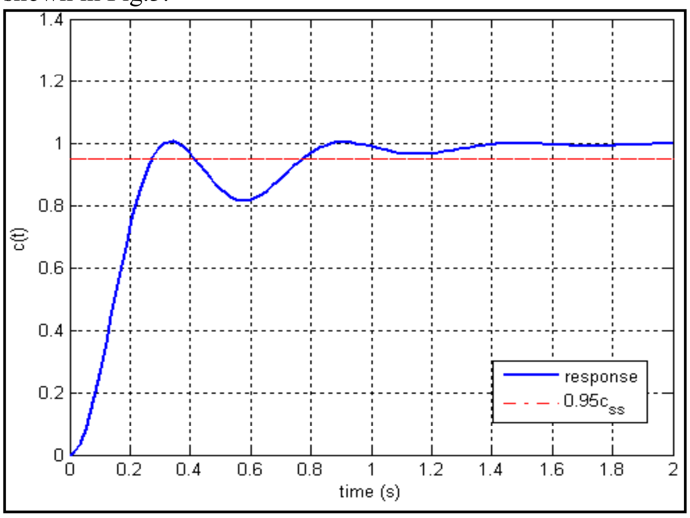

Fig.3 Step response of the PDFF controlled second-order process.

Characteristics of the control system using the tuned PDFF controller:
Maximum percentage overshoot: 0.719 %
Settling time: 0.767 s

IV. Comparison with Standard Forms Tuning and Pid-Controller Application

Tuning using the standard forms

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:

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

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

$K_1 = 1.5503$
$K_3 = 512.6327$

Since the characteristic equation of the closed-loop control system incorporating the PDFF-controller and the second-order process is independent of K_2 of the controller, it has been taken as that obtained in the present work tuning using the IAE objective function.

Using the PID-controller

The PID-controller associated with the present presses of 0.4 rad/s natural frequency and 11 damping ratio was tuned by the author for a minimum ISE objective function. The results are:

$K_{pc} = 328.105$
$K_i = 346.837$
$K_d = 75.525$

The time response of the control system using the present tuning of the PDFF controller , the standard forms tuning and the PID-controller use is shown in Fig.4.

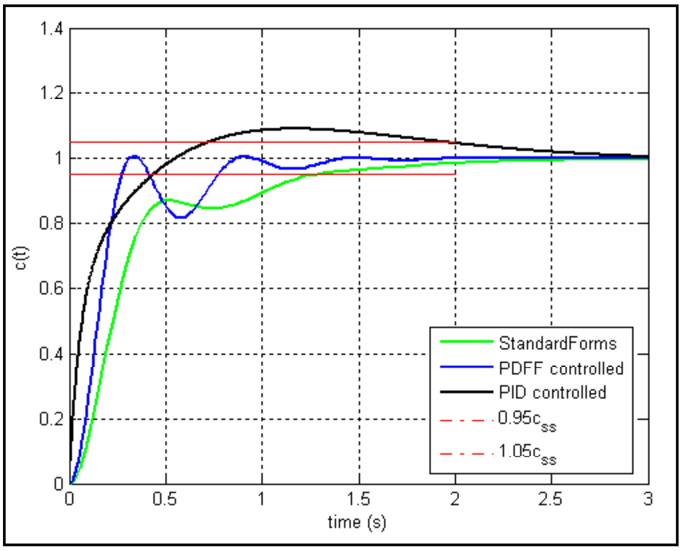

Fig. 4: Step response comparison.

The characteristics of the control system are compared in Table 1:

Table 1: Comparison of control system performance

	PDFF-controller (present tuning)	PDFF-controller (standard forms tuning)	PID-controller (ISE tuned)
Maximum percentage overshoot (%)	0.719	0	8.975
Settling time (s)	0.770	1.263	1.939

V. Conclusions

- It is possible to increase the speed of the process response through using the PDFF-controller.
- Through using a PDFF-controller it was possible to reduce the settling time from about 145.6 seconds to about 0.77 seconds indicating the fast settlement of the controlled process.
- The proposed tuning approach of the PDFF-controller was comparable with the tuning results using the standard forms and with using a PID-controller instead of the PDFF-one.
- The maximum percentage overshoot is reduced from 8.98 % with PID-controller to only 0.72 % with the PDFF-controller.
- The settling time was less than that using the standard forms by 39 % .
- The settling time was less than that using the PID-controller by 83.8 % .

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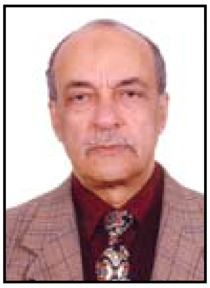
Biography



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