Tuning Of A PID With First-Order-Lag Controller Used With A Highly Oscillating Second-Order Process

Galal A. Hassaan

Abstract: High oscillation in industrial processes is something undesired and controller tuning has to solve this problems. PID with first-order-lag is a controller type of the PID-family which is suggested to overcome this problem. This research work has proven that using the PID is capable of solving the dynamic problems of highly oscillating processes but with less efficiency than other PID-based controller types. A second order process of 85.45 % maximum overshoot and 8 seconds settling time is controlled using a PID controller with first-order-lag (through simulation). The controller is tuned by minimizing the sum of square of error (ISE) of the control system using MATLAB. The MATLAB optimization toolbox is used assuming that the tuning problem is an unconstrained one. The result was reducing the overshoot from 85.45 % to 15.9 % and decreasing the settling time from 8 seconds to only 0.552 seconds. The performance of the control system using a PID with first-order-lag controller using the present tuning technique is compared with that using the ITAE standard forms tuning technique

Index Terms Highly oscillating second-order process ; improving control system performance ; PID with first-order-lag controller, controller tuning ; .

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1 INTRODUCTION

Highly oscillating response is present in a number of industrial processes incorporating low damping levels. Conventionally, the PID controller is used and tuned for better performance of the control system. The PID with first-order-lag controller is one of the next generation to PID controllers where research and application is required to investigate its effectiveness compared with PID controllers. Poulin , Pomerleau, Desbiens and Hodouin (1996) described the design of an auto-tuning and adaptive PID controller. The controller can control processes with stable and unstable zeros, processes with integrator and unstable processes [1]. Seraji (1998) introduced a class of simple nonlinear PID-type controllers comprising a sector-bounded nonlinear gain in cascade with a linear fixed-gain P, PD, PI or PID controller [2]. Lelic (1999) extracted the essence of the most recent development of PID control during the 1990's based on a survey of 333 papers published in various journals [3]. Hamdan and Gao (2000) developed a modified PID (MPID) controller to control and minimize the hysteresis effect in pneumatic proportional valves. The modified controller showed better command following and disturbance rejection qualities than other types [4]. Skogestad (2001) presented an analytical tuning rules as simple as possible but resulting in a good closed-loop behavior. He approximated the process by a first-order plus delay and used a single tuning rule [5]. Podlubny, Petras, Vinagre, O'Leary and Dorcak (2002) presented an approach for the design of analog circuits implementing fractional-order controllers based on the use of continued fraction expansions for the control of very fast processes [6]. Araki and Taguchi (2003) surveyed the important results about two degree of freedom PID controllers including equivalent transformations, the effect of 2DOF structure and relation to the preceded derivative PID and the I-PD controllers [7]. Astrom and Hagglund (2004) presented a design method used to maximize the integral gain subject to a robust constraint giving the best reduction of load disturbance . They revised tuning of PID controllers in the spirit of Ziegler and Nichols technique [8]. Su, Sun and Duan (2005) proposed an enhanced nonlinear PID controller with improved performance than the conventional linear fixed-gain PID controller. They incorporated a sector-bounded nonlinear gain in cascade with the conventional PID controller [9]. Killingsworth and Krstic (2006) presented a method for optimizing the step response of a closed-loop system consisting of a PID controller and an unknown plant with a discrete version of extremum seeking by minimizing a cost function quantifying the performance of the PID controller [10]. Arvanitis, Pasgianos and Kalogeropoulos (2007) investigated the control of unstable second order plus dead-time process using PID-type controllers. They proposed tuning rules based on the satisfaction of gain and phase margin specifications [11]. Madady (2008) proposed a PID type with iterative learning control update law to control discrete-time SISO linear time-invariant systems performing repetitive tasks. He proposed an optimal design method to determine the PID parameters [12]. Coelho (2009) proposed a tuning method to determine the parameters of PID control for an automatic regulator voltage system using chaotic optimization approach based on Lozi map [13]. Khare (2010) developed an internal model mode based PID controller to control the temperature of outlet fluid of the heat exchanger system. His controller demonstrated 84 % improvement in overshoot and 44 % improvement in settling time compared to the classical controller [14]. Ntogramatzidis and Ferrante (2011) introduced a range of techniques for the exact design of PID controllers for feedback control problems involving requirements on the steady-state performance and standard frequency domain specifications. The control parameters had to be calculated on-line meaning that their techniques appear convenient with adaptive and self-tuning control strategies [15]. Yu, Wilson, Currie and Young (2012) investigated the performance of industrial PI and PID controllers in the presence of sampling jitter showing that the derivative component of the PID controller causes excessive controller

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sensitivity to sampling jitter [16]. Abdul-Ghaffar, Ibrahim and Azzam (2013) considered the stabilization of a synchronous machine connected to an infinite bus via PID controller. They tuned the controller parameters using the hybrid Particle Swarm-Bacteria Foraging Optimization [17].

2 ANALYSIS

Process:
The process is a second order process having the parameters:
Natural frequency: $\omega_n = 10$ rad/s
Damping ratio: $\zeta = 0.05$

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:

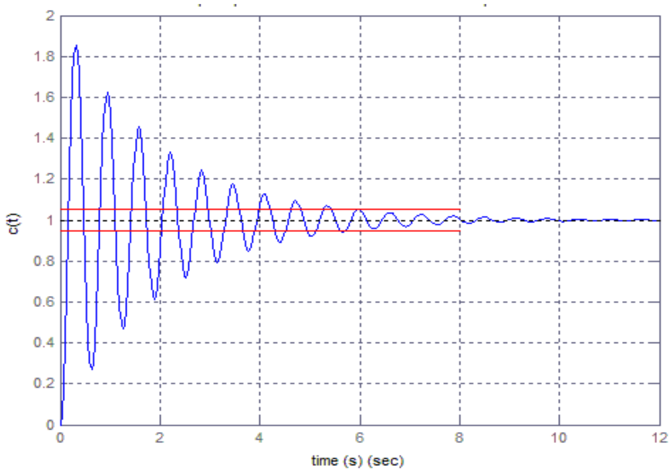

Fig.1 Step response of the uncontrolled process.

The severity of the process oscillations is measured by its maximum percentage overshoot. It has a maximum overshoot of 85.4 % and an 6 seconds settling time.

Controller:
The controller used in this study is a proportional + integral + derivative (PID) with first-order-lag controller. The output of the its PID-module will input to a frst-order module producing the controller output. It has a transfer function $G_c(s)$ given by [18]:

$$G_c(s) = [K_{pc} + (K_i/s) + K_d s]\,[1 / (1 + Ts)] \qquad (2)$$

Where:

K_{pc} = Proportional gain
K_i = Integral gain
K_d = Derivative gain
T = Time constant of the first-order lag.

i.e. the controller has 4 parameters to be identified to control the process and produce a satisfactory performance.

Control System Transfer Function:
Assuming that the control system is a unit feedback one, its transfer function becomes:

$$M(s) = (b_0 s^2 + b_1 s + b_2) / (a_0 s^4 + a_1 s^3 + a_2 s^2 + a_3 s + a_4) \qquad (3)$$

where:

$b_0 = \omega_n^2 K_d$
$b_1 = \omega_n^2 K_{pc}$
$b_2 = \omega_n^2 K_i$
$a_0 = T$
$a_1 = 1 + 2\zeta\omega_n T$
$a_2 = 2\zeta\omega_n + \omega_n^2 T + \omega_n^2 K_d$
$a_3 = \omega_n^2 + \omega_n^2 K_{pc}$
$a_4 = \omega_n^2 K_i$

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 [19].

3 CONTROLLER TUNING

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

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

where c_{ss} = steady state response of the system. The performance of the control system is judged using two time-based specifications:

(a) Maximum percentage overshoot, OS_{max}
(b) Settling time, T_s

4 TUNING RESULTS

The MATLAB command "*fminunc*" is used to minimize the optimization objective function given by Eq.4 without any parameters ot functional constraints [21]. The results are as follows:

Controller parameters:

K_{pc} = 1.9965
K_i = 17.0000
K_d = 0.1504
T = 0.0030

The time response of the closed-loop control system to a unit step input is shown in Fig.2.

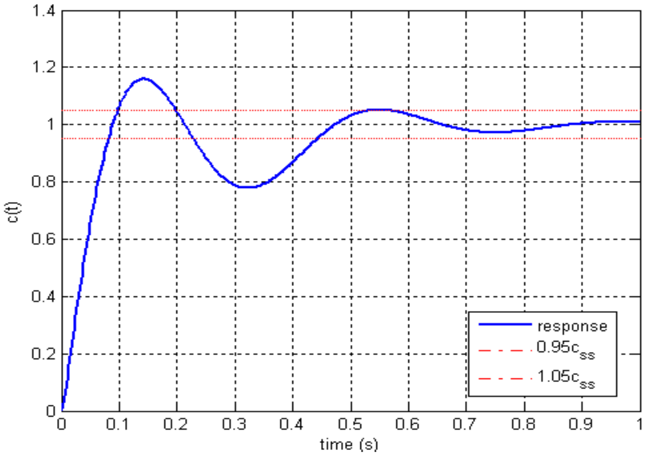

Fig.2 Step response of the PID with first-order-lag controlled second order process.

Characteristics of the control system using the tuned PID with first-order-lag controller:

- Maximum percentage overshoot:	15.9	%
- Maximum percentage undershoot:	24.0	%
- Settling time:	0.552	s

5 COMPARISON WITH STANDARD FORMS TUNING

The control system in terms of its transfer function is a fourth order one. The optimal characteristic equation of such a system with a second-order numerator is given using an ITAE critertion by [23]:

$$S^4 + 3.71\omega_o s^3 + 7.88\omega_o^2 s^2 + 5.93\omega_o^3 s + \omega_o^4 \qquad (5)$$

Comparing Eq.5 with the corresponding one in Eq.3 we get 3 equations in ω_o, K_{pc}, K_i, K_d and T. i.e. 4 unknowns and 3 equations. To be able to get the controller parameters using this tuning technique, one of the parameters has to be assumed. It was reasonable from the equations to assign T (it was taken as 0.003 as obtained in the present tuning technique using the ISE criterion). The rest of the controller parameters were calculated as:

K_{pc} = 131.826
K_i = 2038.857
K_d = 1.9261
T = 0.003

The time response of the control system using this standard forms tuning technique is shown in Fig.3:

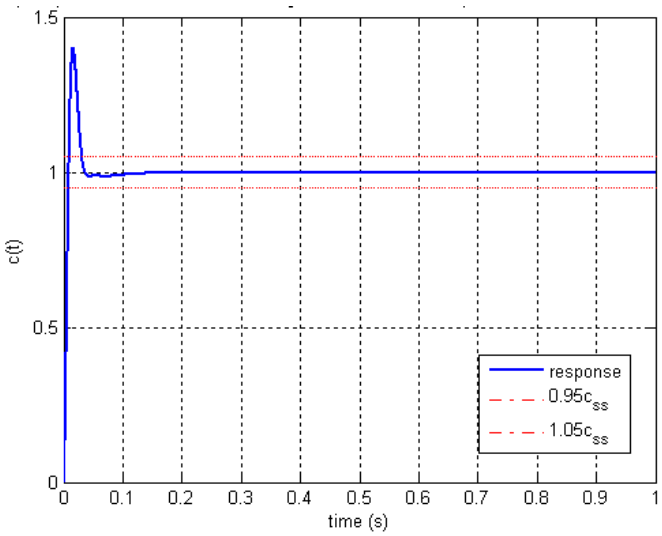

Fig.3 Step response of the PID with first-order-lag controlled second order process using the ITAE standard forms.

Characteristics of the control system using the standard forms tuning technique:

- Maximum percentage overshoot:	40.0	%
- Maximum percentage undershoot:	1.4	%
- Settling time:	0.032	s

6 CONCLUSIONS

- It is possible to suppress higher oscillations in processes through using the PID with first-order-lag controller. , PIDF [24] or PIPD [25] controllers.
- This controller is not as efficient as the PIDF of PIPD controllers.
- Through using a PID with first-order-lag controller it was possible reduce the settling time from about 8 seconds to about 0.55 seconds indicating the fast settlement of the controlled process.
- The PID with first-order-lag controller could not reduce the maximum percentage overshoot than 16 % .
- Tuning the controller using standard forms produced a time response of the closed loop system having more overshoot (40 %) and a spike-nature response.
- However, the settling time and maximum undershoot were better in the standard forms technique than the present technique based on ISE error criterion.

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