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

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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; .

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 plants [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.
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:
\[
M_p(s) = \frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}
\]

(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.](image)

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 first-order module producing the controller output. It has a transfer function \( G_c(s) \) given by [18]:
\[
G_c(s) = \frac{[K_p + (K_i/s) + K_ds]}{[1 / (1 + Ts)]}
\]

(2)

Where:
- \( K_p \) = 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:
\[
M(s) = \frac{b_0s^2 + b_1s + b_2}{(a_0s^4 + a_1s^3 + a_2s^2 + a_3s + a_4)}
\]

(3)

where:
- \( b_0 = \omega_n^2K_d \)
- \( b_1 = \omega_n^2K_p \)
- \( b_2 = \omega_n^2K_i \)
- \( a_0 = T \)
- \( a_1 = 1 + 2\zeta\omega_n T \)
- \( a_2 = 2\zeta\omega_n + \omega_n^2T + \omega_n^2K_d \)
- \( a_3 = \omega_n^2 + \omega_n^2K_p \)
- \( a_4 = \omega_n^2K_i \)

System Step Response:
A unit step response is generated by MATLAB using the numerator and denominator 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:
\[
F = \int [c(t) - c_{ss}]^2 \, dt
\]

(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 or functional constraints [21]. The results are as follows:

Controller parameters:
- \( K_p \) = 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.
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 criterion by [23]:

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

Comparing Eq.5 with the corresponding one in Eq.3 we get 3 equations in $$\omega_n$$, $$K_{pc}$$, $$K_i$$, $$K_d$$ 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 ITAE 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.](image)

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

It is possible to suppress higher oscillations in processes through using the PID with first-order-lag controller. P, 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.

REFERENCES


BIOGRAPHY

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