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Tuning of a Modified I-PD Controller for use with a highly Oscillating Second-order-like Process

Galal Ali Hassaan
(Department of Mechanical Design & Production, Faculty of Engineering, Cairo University, Egypt
Email: galalhassaan @ymail.com)

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Abstract:

This paper presents a tuning approach for a modified I-PD controller to be used with a highly oscillating second-order-like process. The MATLAB program is used through its optimization toolbox to tune the controller subjected to three functional constraints. The functional constraints are selected to produce good performance of the control system regarding its transient characteristics. The tuning technique used is compared with another technique and the effectiveness of the controller is investigated through comparison with using the ITAE standard form technique, with the I-PD original controller and with a conventional PID controller.

Keywords — **Modified I-PD controller, controller tuning, control system performance**.

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I. INTRODUCTION

This is one of the controllers investigated by the author to improve the performance of linear control systems and get red of the drawbacks of using the conventional PID controller.

Kondo and Ochi (2010) described a design method of an I-PD controller for a SISO plant. They presented examples to demonstrate the effectiveness and usefulness of their proposed method. The I-PD structure they used consisted of one integral block acting on the error signal and a loop comprising a PD-controller in its feedback [1]. Prasad, Varghese and Balakrishnan (2012) designed an I-PD controller to control a first order lag integrating plus time delayed (FOLIPD) plant. They compared their tuning technique with two other techniques including Ziegler-Nichols one [2]. Mechizuki and Ichihara (2013) in their paper about I-PD controller design when used with ball and plate system designed the controller using the generalized Kalman-Yakubovich-Popov lemma for the ball and plate. The closed loop control system they proposed had an I-action acting on the main error of the control system, P+D actions and a low pass filter acting in the feedback path. They used the low pass filter to reduce the influence of the noise measurement from the camera [3]. Hassaan (2014) in his paper about tuning an I-PD controller used with a highly second order process tuned the controller using an ISE criterion and the MATLAB optimization toolbox. He could get rid of the kick associated with PID controller application and reduce the settling time to only 1.46 s [4].

Puangdownreong, Nawikavatan and Thammarat (2016) proposed using an I-PD controller to eliminate the set-point kick caused due to using a PID controller. The process they controlled had a third order model and they tuned the I-PD controller using the Cuckoo search optimization resulted in a step response of the control system having 4.2 % maximum overshoot and an 0.21 s settling time [5]. Sain (2016) designed PID, I-PD and PD-PI controllers for use with the nonlinear ball and beam system. He linearized the nonlinear model and tuned the controllers using the ITAE criterion [6]. Panjaitan, Kurnianto, Sanjaya and Turner (2017) applied an I-PD controller to control an islanded micro grid system. The results showed good reference tracking capabilities during set-pont and load changes compared with PID control [7]. Kaya (2018) applied the I-PD controller to improve the performance of unstable processes comparing with PID and I-PD design methods. He used the IST^2E criterion to tune the control providing good control system performance [8].

II. PROCESS

The controlled process is second-order-like process having the transfer function, $G_p(s)$:

$$G_p(s) = \omega_n^2 / (s^2 + 2\zeta\omega_n s + \omega_n^2) \quad (1)$$

Where:

ω_n = process natural frequency = 10 rad/s

ζ = process damping ratio = 0.05

III. THE I-PD CONTROLLER

The structure of an I-PD controller for the control of a process was proposed to help in getting rid of the kick associated with using a PID controller and shown in Fig.1 [2] . The controller shown in Fig.1 has three parameters: the integral time constant τ_i , the proportional gain K_p and the derivative time constant τ_d. This control was used by the author to control a highly oscillating process having 85.45 % maximum overshoot and 8 s settling time.

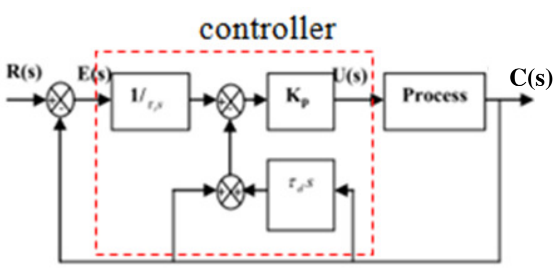

Fig.1 I-PD controlled process [2].

In a modified I-PD controller, the integral gain K_i and the derivative gain K_d are used instead of the integral time constant τ_i and the derivative time constant τ_d. The new block diagram of the closed loop control system is shown in Fig.2

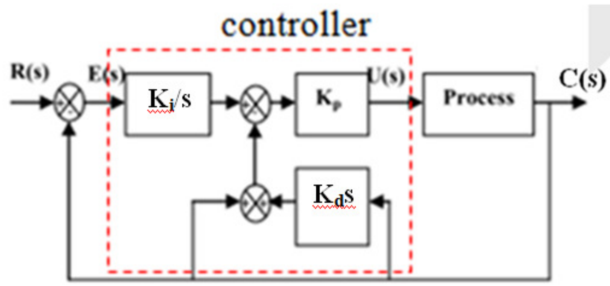

Fig.2 Modified I-PD controlled process.

In our present modification, the mathematical model of the modified I-PD controller relating its output U(s) to its two inputs E(s) and C(s) as clear from the controller block diagram in Fig.2 is given by:

$$U(s) = K_p\{(K_i/s)E(s) - (1 + K_d s)C(s) \quad (2)$$

With E(s) = R(s) – C(s), Eq.2 becomes:

$$U(s) = (K_pK_i/s)R(s) - [(K_pK_i/s)+K_p(1+K_d s)]C(s) \quad (3)$$

The modified I-PD controller has three parameters:

- Proportional gains, K_p
- Integral gain, K_i
- Derivative gain, K_d

IV. CONTROL SYTEM TRANSFER FUNCTION

As the process transfer function, $G_p(s)$ is related to the controller output U(s) and process output C(s) through:

$$G_p(s) = C(s) / U(s) \quad (4)$$

The closed loop transfer function of the control system is obtained by combining Eqs.1, 3 and 4 and given by:

$$M(s) = b_0 / (a_0 s^3 + a_1 s^2 + a_2 s + a_3) \quad (5)$$

Where:

$b_0 = \omega_n^2 K_pK_i$

$a_0 = 1$

$a_1 = 2\zeta\omega_n + \omega_n^2 K_pK_d$

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

$a_3 = \omega_n^2 K_p K_i$

V. CONTROLLER TUNING AND SYTEM TIME RESPONSE

The controller parameters are tuned as follows:

- The control and optimization toolboxes of MATLAB are used to assign the three parameters of the controller [9].
- The integral of the square of time square multiplied by error (IST^2E) suggested by Kaya [8] is chosen as an objective function for the optimization process.
- Three functional constraints are set for the closed-loop control system: maximum percentage overshoot, settling time and a stability constraint derived from the Routh-Hurwitz criterion for control system stability.
- The step response of the closed-loop control system is plotted using the command '*step*' of MATLAB [10].
- The controller is tuned using the above approach for the second order-like process with $\zeta = 0.05$ and equivalent natural frequency $\omega_n = 10$ rad/s.
- The time-based specifications of the closed-loop control system are extracted using the MATLAB command '*stepinfo*' [11].
- The tuning parameters of the modified I-PD controller are:

$$K_p = 20.0659$$
$$K_i = 13.7404$$
$$K_d = 0.0299$$

- The unit step response of the control system incorporating the tuned modified I-PD controller is shown in Fig.3.
- The step time response of Fig.3 reveals the following time-based specifications of the closed control system incorporating the modified I-PD controller:

• Maximum percentage overshoot: 0.051 %
• Settling time: 0.148 s
• Steady state error: 0

- The modified I-PD controller could eliminate completely the kick associated with the classical PID controller.

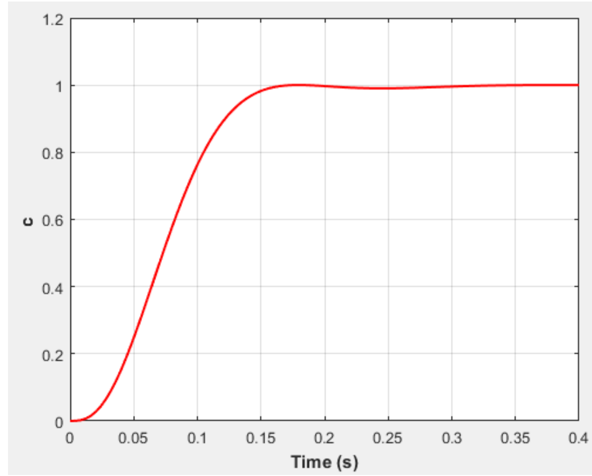

Fig.3 Modified I-PD controlled second order process.

VI. COMPARIZON WITH MINIMUM ITAE STANDARD FORMS TUNING

- The parameters of the modified I-PD controller is tuned using the minimum ITAE standard forms of Graham and Lathrop [12]. The resulting controller parameters are:

$$K_p = 20.0659$$
$$K_i = 15.2846$$
$$K_d = 0.0268$$

- The unit step time response of the closed loop control system incorporating the modified I-PD controller and the process with $\zeta = 0.05$ and $\omega_n = 10$ rad/s is shown in Fig.4 for both tuning techniques.
- The performance characteristics of the control system for both tuning techniques are as follows:

• The maximum percentage overshoot is 0.051 using the presented tuning technique compared with 1.975 % using the minimum ITAE standard forms of Graham and Lathrop.
• The settling time (within ± 2 % band) is 0.148 s compared with 0.241 s using the minimum ITAE standard forms of Graham and Lathrop.

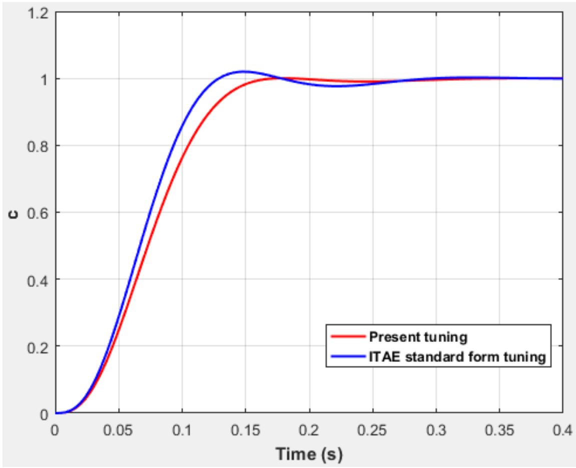

Fig.4 Comparison between two tuning techniques.

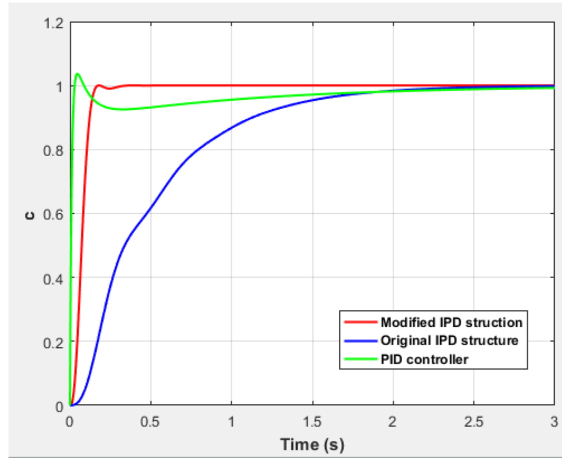

Fig.5 Comparison between three controllers.

VII. COMPARIZON WITH PID AND I-PD CONTROLLERS

- To investigate the effectiveness of the modified controller regarding kick elimination, it was compared with using a classical PID controller to control the second order process under study.
- The PID controller was tuned by the auther when used with underdamped second order processes and had the tuned parameters [13]:

$K_p = 9.9981$
$K_i = 9.0021$
$K_d = 0.9892$

- The Un-modified I-PD controller was tuned by the author and had the tuned controller parameters [14]:

$K_p = 1.7523$
$K_i = 5.3314$
$K_d = 0.1113$

- The unit step response of the closed loop control system incorporating the three controllers used with the highly oscillating process is shown in Fig.5.
- The time based characteristics of the control system using the three controllers are compared in Table 1.

TABLE 1
CHARACTERISTICS COMPARISON USING THREE CONTROLLERS

Controller	I-PD	Modified I-PD	PID
OS_{max} (%)	0	0.051	3.648
T_s (s)	1.898	0.148	1.897

VIII. CONCLUSIONS

- The I-PD controller was modified by replacing its time constants τ_i and τ_d parameters by K_i and K_d.
- It was used to suppress the high oscillations of a second-order-like process.
- It was tuned using the MATLAB optimization toolbox.
- Three constraint functions were used to provide good performance for the closed loop control system.
- The IST^2E error criterion was used as an objective function for the constrained optimization problem of the controller tuning.
- The tuning technique used was compared with another one using the minimum ITAE standard forms.

- The performance of the control system in terms of its unit step time response was compared with that using a classical PID controller and an un-modified I-PD controller.
- The time response kick was authorized when using the PID controller.
- The time-based specifications of the control system were compared for the three controllers: I-PD, modified I-PD and PID controllers.
- The modified I-PD controller was superior compared with the un-modified I-PD producing a very fast step time response with very low maximum percentage overshoot.

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BIOGRAPHY

Galal Ali Hassaan

- Emeritus Professor of System Dynamics and Automatic Control.
- Has got his B.Sc. and M.Sc. from Cairo University in 1970 and 1974.
- Has got his Ph.D. in 1979 from Bradford University, UK under the supervision of Late Prof. John Parnaby.
- Now with the Faculty of Engineering, Cairo University, EGYPT.
- Research on Automatic Control, Mechanical Vibrations , Mechanism Synthesis and History of Mechanical Engineering.
- Published 255 research papers in international journals and conferences.
- Author of books on Experimental Systems Control, Experimental Vibrations and Evolution of Mechanical Engineering.
- Chief Justice of the International Journal of Computer Techniques.
- Member of the Editorial Board of some International Journals including the International Journal of Computer Techniques.
- Reviewer in some international journals.
- Scholars interested in the author's publications can visit:

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